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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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STRUCTURE OF THE WHITE RIVER PLATEAU NEAR GLENWOOD SPRINGS, COLORADO

BY WILLIAM CHARLES MACQUOWN, JR.

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ABSTRACT

In the White River Plateau, near Glenwood Springs, Colorado, quartz-biotite schists, tentatively correlated with the Idaho Springs formation, and later granites are probably of Archean age. The pre-Pennsylvanian formations, which underlie the greater part of the plateau near Glenwood Springs, are persistent lithologically, although thicker in the north and east. Post-Mississippian strata and volcanics are described briefly.

The schistosity of metamorphosed Archean sediments strikes N. 70° W. and probably indicates an early pre-Cambrian structural trend. Minor pre-Laramide or early Laramide movements may have been expressed in a well-developed joint system in the Cambrian Sawatch quartzite of Glenwood Canyon. The sinuous Grand Hogback monocline includes structural elements of the border zone between the White River Plateau and the Uinta Basin and swings from west to south in the area mapped. Locally the steeply dipping limb of the monocline is interrupted by the Glenwood Springs syncline, which is bordered on the northeast by the broad, regional White River Plateau arch and on the southwest by the Grand Hogback anticline. The Flattops arch and the Glenwood Canyon fold trend respectively north and east. Faulting is of the high-angle, gravity type characteristic of plateau areas. Longitudinal, transverse, and oblique faults are described in relation to associated folds. This classification of faults is employed because of the complexity of trends brought about by the swinging of the regional structure from north-south to east-west and the development of cross structures north of Glenwood Springs. Plateau arching, monoclinal flexing, and widespread normal faulting were probably initiated during the late Cretaceous and continued through middle Eocene time. Differential uplift between the White River Plateau and the Sawatch Range is reflected in the Glenwood Canyon fold and associated faults. Cross structures were developed, probably through torsion. The westerly trend is probably localized in part by the basement structure. Although some horizontal movement occurred, the dominant orogenic movement appears to have been vertical. Minor folding in the incompetent Pennsylvanian formations may have been controlled largely by doming of associated gypsum. Later uplifts have probably taken place through broad regional arching and renewal of movement along fault planes. The geologic history is summarized graphically in a series of block diagrams.

INTRODUCTION

The Glenwood Springs quadrangle represents an area of half a square degree on the western slope of the Rocky Mountains in northwestern Colorado (Fig. 1). This region includes the southeastern two-thirds of the White River Plateau and minor extensions of the Uinta and Eagle basins. The northern third of the Glenwood Springs quadrangle is almost covered by thick basaltic lava flows of the Flattops Mountains. The present discussion is limited to the southern two-thirds of the quadrangle.

The writer spent 15 weeks during the summers of 1941 and 1942 in the field. Geological data were plotted on the Glenwood Springs topographic quadrangle map enlarged from a scale of 1/125,000 to 1/62,500. An area north of the Colorado River

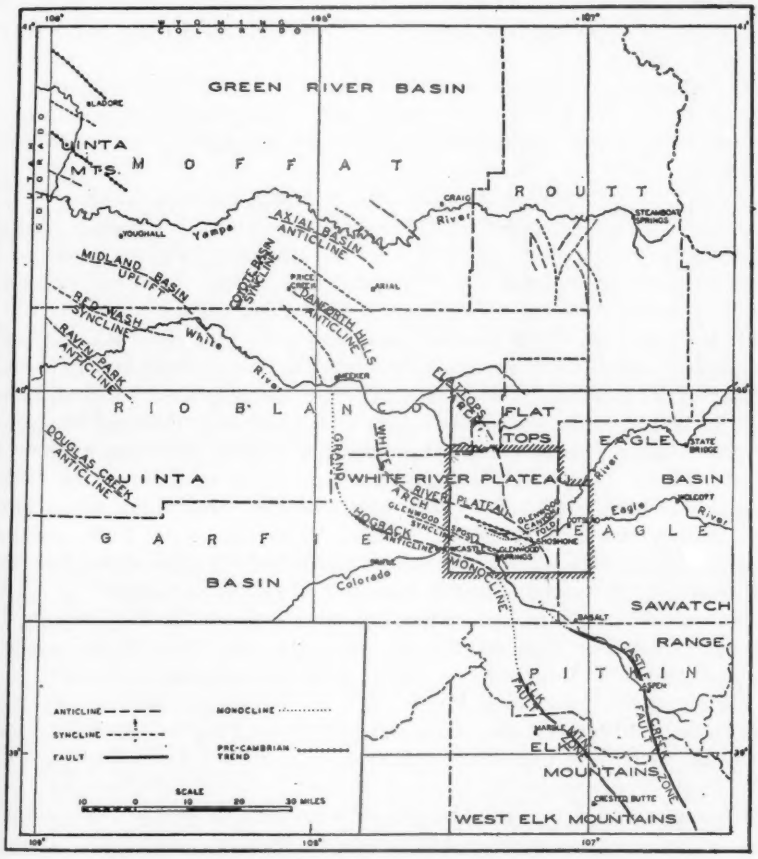

FIGURE 1.—*Index map: structural trends in northwestern Colorado*

Area studied outlined by diagonal lines

of approximately 300 square miles was mapped in considerable detail. In addition, a reconnaissance survey included the geology of the entire southern two-thirds of the quadrangle. Field work in the Glenwood Springs region is made difficult by the strong relief and the lack of roads. Equipment was packed on horseback from Glenwood Springs or Sweetwater Lake to six base camps.

PREVIOUS WORK

The first geological reports referring to the Glenwood Springs region are those of Hayden (1878) on Colorado and adjacent territory and include a geologic reconnais-

sance map. Reports of C. A. White, F. M. Endlich, and A. C. Peale in the same survey (1878) give the general features of the geology of the White River Plateau.

Van Diest (1888) and Lakes (1890) described volcanism in the Glenwood Springs region and adjacent areas in Colorado. Hills (1891) did reconnaissance work in the White River Plateau and considered regional structural relationships involving the Glenwood Springs area.

The paleontology of the Devonian "Ouray fauna" (fauna of the Dyer dolomite) and generalized measured sections of the pre-Pennsylvanian strata in Glenwood Canyon near Glenwood Springs and Shoshone were included in reports by Girty (1900; 1904) and Kindle (1909).

Lakes (1905) speculated on the origin of hot springs in Colorado, including those at Glenwood Springs. Campbell (1922) has given an account of the geology along the Colorado River right of way of the Denver and Rio Grande Railroad which passes through the southern part of the Glenwood Springs region. Campbell included in his report a reconnaissance geologic map 20 miles wide along the railroad.

R. T. Chamberlin (1923) described and illustrated a generalized structural cross section from Lyons, Colorado, across the Rockies to the Glenwood Springs region to support evidence of crustal shortening as applied to the wedge theory of diastrophism.

Kirk (1931) discussed the correlation of the Devonian rocks through Colorado and suggested changes in the Glenwood Springs stratigraphic section as measured by Kindle (1909). Landon (1933) described and dated the volcanism of the Dotsero crater. Vanderwilt and Fuller (1935) gave a detailed stratigraphic section of the pre-Pennsylvanian near Glenwood Springs. Vanderwilt (1935; 1937) considered regional structural correlations involving a northward extension of structure from Aspen and the Snowmass Mountain areas toward Glenwood Springs.

Heaton (1933) included a generalized measured section of the Carboniferous and Mesozoic strata near Glenwood Springs. Lovering and Johnson (1933) correlated the Paleozoic rocks near Glenwood Springs with other localities in Colorado.

Bassett (1939) measured and described detailed stratigraphic sections of the Paleozoic strata near Dotsero at the eastern end of Glenwood Canyon. Brill (1944) correlated the questionable Carboniferous-Triassic strata of the Glenwood Springs region with adjacent regions.

Previous work has thus provided general reconnaissance data of the geology, as well as several detailed stratigraphic sections, in the Glenwood Canyon. However, the hinterland of the White River Plateau has been neglected because of the difficult terrain.

The purpose of this paper is to present the character, origin, and development of local structure in relation to regional structural trends.

ACKNOWLEDGMENTS

To Dr. C. M. Nevin the writer is grateful for helpful criticism of the manuscript and suggestions relating to structural problems. A grant from the Charles Bean De Long Graduate Research Fund of Cornell University is appreciated. For assistance in the field, special thanks are due T. I. Kennedy and R. H. MacQuown. Material aid in preparation of the diagrams was rendered by V. J. MacQuown.

FIGURE 1. PRE-PENNSYLVANIAN ROCKS NEAR SHOSHONE
P€—Archean, €S—Sawatch quartzite, €D—Dotsero dolomite, DC—Chaffee formation, ML—Leadville limestone.

FIGURE 2. JOINTING IN THE SAWATCH QUARTZITE
One-quarter mile west of the Eagle-Garfield County line.

GLENWOOD CANYON

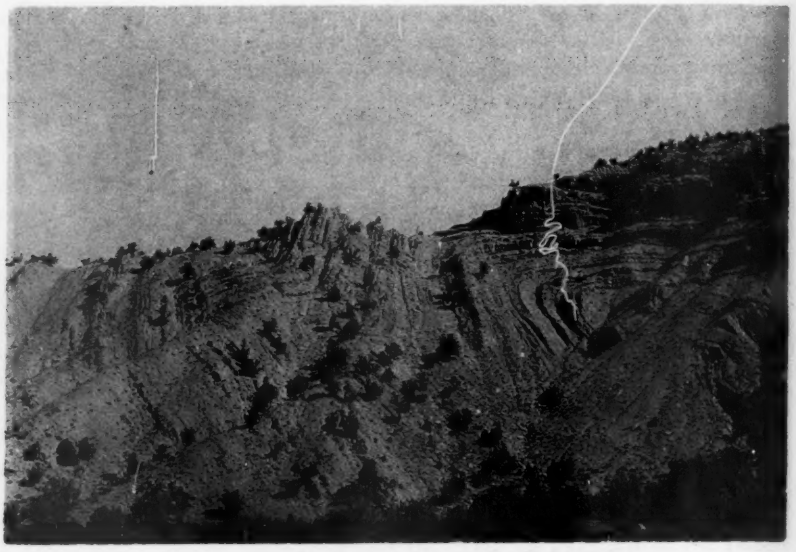

FIGURE 1. MINOR FOLDING OF INCOMPETENT PENNSYLVANIAN ROCKS
East of Sweetwater Lake.

FIGURE 2. LONGITUDINAL STEP FAULTS ALONG LOWER CANYON CREEK
ϵS—Sawatch quartzite, ϵD—Dotsero dolomite, DC—Chaffee formation, ML—Leadville limestone.

STRATIGRAPHY

GENERAL

The section on stratigraphy, which is presented as a background for structural discussion, is largely in chart form with a brief accompanying text. A generalized columnar section of the entire sequence of formations with the names and thicknesses of individual formations appears in Figure 2. This chart combines data from several sections measured in reconnaissance (T. 6 S. Rs. 89 and 90 W.). A more detailed columnar section of the pre-Pennsylvanian rocks (Fig. 3) is described under Paleozoic stratigraphy.

Pre-Cambrian metamorphosed sedimentary rocks and Paleozoic strata of pre-Pennsylvanian age underlying the White River Plateau north of Glenwood Springs yield the principal clues to the structural development of the plateau proper (Pl. 1, fig. 1). Carboniferous, Jurassic, Cretaceous, and early Tertiary formations, which are prominent along the flanks of the plateau, reflect in particular structural conditions in the border zone between the White River Plateau and Uinta Basin (Pl. 3).

PRE-CAMBRIAN

The pre-Cambrian rocks of the Glenwood Springs region are divided into early quartz-biotite schists and greenstones and later granites containing numerous pegmatite dikes. Occasional interbedded hornblende schists and gneisses are possibly of volcanic origin. The usual schist, however, contains little feldspar, hornblende, or other minerals indicative of an igneous origin. Although metamorphism has usually removed all traces of former structure, the original rock is considered to have been sedimentary and is correlated with extensive schistose rocks of known sedimentary origin in adjacent areas. In the Sawatch Range, 30 miles to the southeast of Glenwood Springs, Stark (1934) described similar crystalline gneisses and schists grading into quartzite, marble, and graywacke. According to Lovering (personal communication) "the schists of the Glenwood Springs area may well be the equivalent of the Idaho Springs formation of sedimentary origin."

Granitic intrusions invaded the schists in stocks, sills, dikes, and *lit-par-lit* stringers. The granites and pegmatites in the Glenwood Springs region are everywhere later than the metamorphics, and considerable local *lit-par-lit* injection of the latter was observed.

The contact of the pre-Cambrian with the overlying Cambrian strata is unconformable. A relatively flat surface and decomposition of the pre-Cambrian 10 to 20 feet below the overlying Sawatch quartzite was seen in Glenwood Canyon west of NoName Creek and also east of Dead Horse Creek. A long period of erosion prior to the deposition of the Sawatch quartzite is indicated. These highly folded metamorphics and granites, which are similar to the Archean rocks of the adjacent Sawatch Range, are probably the same age as the latter.

PALEOZOIC

The stratigraphy of the pre-Pennsylvanian formations is given in tabular form (Fig. 3). Four sections measured by the writer were correlated with the Paleozoic

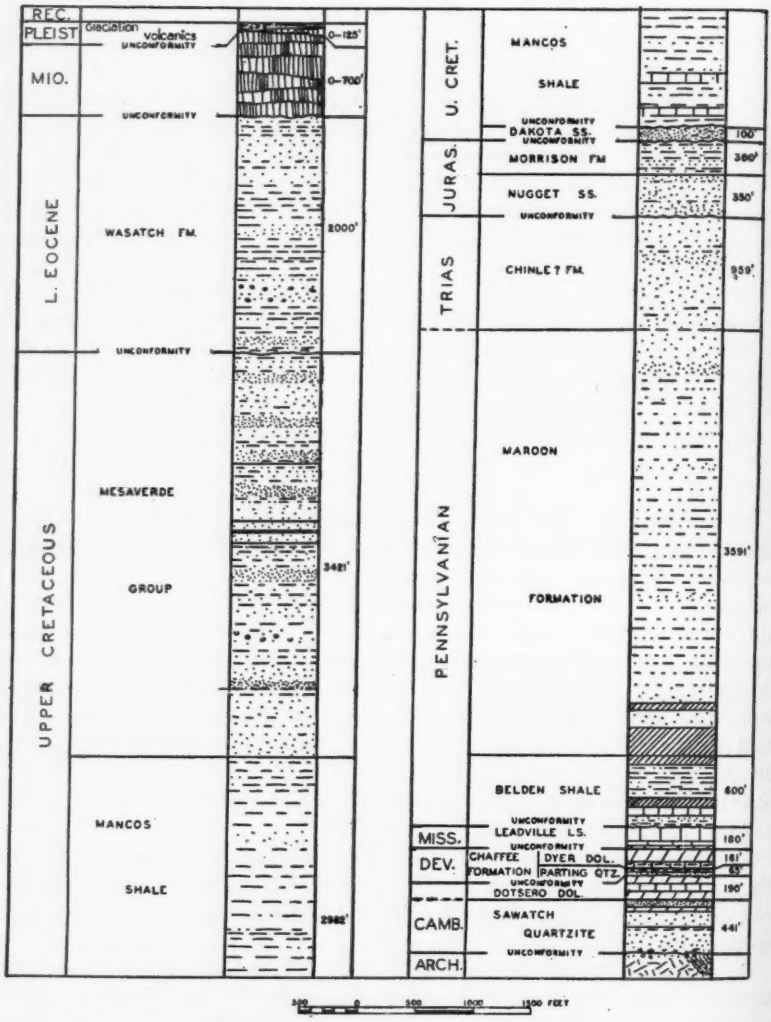

FIGURE 2.—*Generalized columnar section*

section measured by Bassett (1939) near Dotsero, east of Glenwood Springs on the Colorado River. The persistent occurrence, typical lithology, weathering pattern, and fauna of these Paleozoic formations were observed throughout the area studied. A general thickening is evident to the north and east of Glenwood Springs, but thicknesses of individual formations vary locally.

The Carboniferous-Triassic (?) section (Fig. 2) is extremely variable in thickness and lithology, partly because of contortion of the gypsum beds. The terminology is

still in a state of flux, and the boundaries are not easily determined because of a lack of fossils. Brill (1944) believes these rocks of questionable age to be Carboniferous in the Glenwood Springs region.

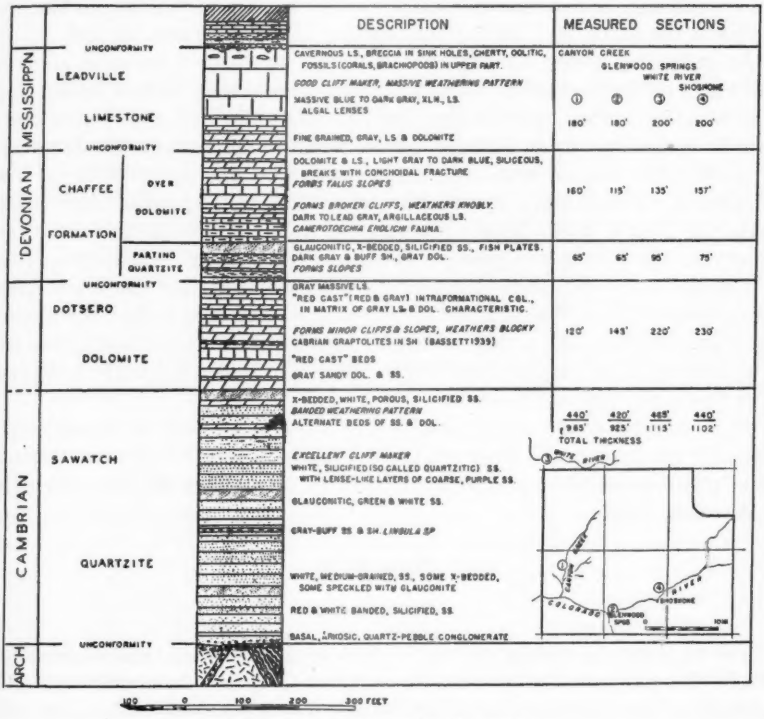

FIGURE 3.—*Pre-Pennsylvanian strata*

POST-PALEOZOIC

Jurassic and Cretaceous strata 7050 feet thick and Eocene beds 2000 feet thick are confined to the Grand Hogback area in the southwestern part of the region (Fig. 2). Fair exposures were examined in reconnaissance on South Canyon Creek.

TERTIARY AND QUATERNARY IGNEOUS ROCKS

INTRUSIVE

Highly weathered porphyry dikes trending N. 65°–70° W. are found in the Sugarloaf Mountain area northeast of Sweetwater Lake. They appear to be similar to those of early Tertiary age in other parts of Colorado.

A few basaltic sills and dikes, presumably of Tertiary age, were observed also.

EXTRUSIVE

Plateau basalt.—Several large high-level discontinuous basaltic outcrops are erosion remnants of a formerly continuous sheet. The flows are highly weathered, but sills,

probably of similar age, are relatively little weathered. On the White River Plateau the basalts are found at elevations of 10,000 to 11,000 feet. To the south they rest on the flanks of a broad anticlinal uplift and are found at elevations of 8000 to 9000 feet. Although the flows are 1500 feet or more in thickness in the Flattops Mountain region to the north, they are not over 700 feet thick in the area mapped.

An underlying erosion surface, which is tilted with the lava, truncates all formations from the Pennsylvanian shales to and including the early Eocene Wasatch beds. The basalt therefore cannot be older than Eocene. However, this erosion surface may be equivalent to the Miocene Gilbert Peak or the questionable Miocene or Pliocene Bear Mountain erosion surfaces described by Bradley (1936) in the Uinta Mountains. Hills (1891) suggested Miocene age because the peneplain surface truncates the slightly folded Eocene Wasatch formation. Since the flows are clearly older than the present topography a Miocene or Pliocene age would appear likely.

Late flows and pyroclastics.—Relatively unweathered local flows that follow present topography were observed in a north-south zone, 5 miles wide, in the eastern part of the area. Willow Peak, a cinder cone, has an associated basaltic, scoriaceous flow. The Dotsero Crater has associated volcanic ash and dust deposits to the north and a lava flow a mile long to the south.

At Sweetwater Lake a recent basaltic flow is overlain by an end moraine and is probably pre-Wisconsin. However, Landon (1933) believed the Dotsero volcanism to be post-Wisconsin because the flow blocked the Eagle River which in turn eroded a Wisconsin terrace.

STRUCTURE

PRE-CAMBRIAN

The schistosity of metamorphosed Archean sediments in the area studied strikes N. 70° W. and probably indicates an early pre-Cambrian structural trend. This schistosity is best developed in two parallel mile-wide zones about 4 miles apart, which dip toward each other at high angles (Fig. 1) These zones were traced from Shoshone to the western border of the area studied. Later intrusions of pre-Cambrian granite disturbed the regularity of the regional pattern and locally controlled the direction and amount of dip of the schists. The granite may have intruded the metamorphics along the northwest trend and, spreading out laterally and upward, could have given the adjacent schist an apparent synclinal structure. Or, the granite may have intruded a pre-Cambrian syncline and modified the existing dip of the schistosity only slightly (Fig. 5, A). The existence of similar funnel-shaped bodies of granite in the Front Range has been demonstrated (Lovering, personal communication).

East-west and northeast trends of the pre-Cambrian of central Colorado and southern Wyoming are well established (Lovering, 1933) but the recognition of trends in western Colorado is hampered by lack of exposures. However, the northwestern trend near Glenwood Springs is not unique. Similar ones have been reported from the eastern Uinta Mountain extension in Colorado (Lovering, 1933), from the southern Sawatch Mountains (Stark, 1934), and from the Gunnison River region (Hunter,

1925). The strike of the schistosity in the Glenwood Springs region suggests a pre-Cambrian structural trend in northwestern Colorado from the White River Plateau to the eastern Uinta Mountains.

JOINTS

All competent rocks in the Glenwood Springs region contain joint sets, but those of the Sawatch quartzite are the best developed. Between Shoshone and Dotsero in Glenwood Canyon an excellent conjugate system of vertical joints was formed in the slightly folded Sawatch. The strikes of 146 selected joints indicate two prominent sets trending N. 15° E. and N. 80° W. (Pl. 1, fig. 2). The average strikes of 96 additional joints measured throughout the region in the Sawatch are almost identical with these. The joints have smooth plane surfaces, appear to have been formed at the same time, and are usually better developed in one direction than in the other.

These joint sets constitute a joint system which was probably formed during an initial stage of uplift prior to folding. Vertical forces operating through the pre-Cambrian basement or compressive lateral stress in a N. 55° E. direction could have produced these joints (Fig. 4, A).

FOLDS

Grand Hogback monocline—The sinuous Grand Hogback monocline (Fig. 1) includes structural elements of the border zone between the White River Plateau and the Uinta Basin. Previously this monocline has been considered a single unit, but detailed work in the Glenwood Springs region indicates the advisability of a threefold division. The steeply dipping limb of the monocline is interrupted by a synclinal structure named the Glenwood Springs syncline. This is bordered on the northeast by a broad regional fold named the White River Plateau arch and on the southwest by the Grand Hogback anticline (Pl. 3)

The White River Plateau arch underlies the entire southern part of the plateau and plunges to the southeast in Glenwood Canyon where an excellent section is exposed between Dotsero and Glenwood Springs. The southwestern limb is steep and cut by parallel normal strike faults. West of the Glenwood Springs region the structure parallels the Grand Hogback monocline (Fig. 1) and eventually swings to the north. Beyond Meeker the arch may continue northwestward as the Danforth Hills anticline.

The narrow Glenwood Springs syncline is at least 20 miles long and was traced southeast from Newcastle to beyond Cardiff (Fig. 1). The true symmetry of the fold is difficult to determine, because of involved minor folding of the gypsum and associated incompetent Pennsylvanian strata.

The Grand Hogback anticline forms the front of the Grand Hogback monocline and disappears with the plunging of the Glenwood Springs syncline (Fig. 1). The southwestern limb is steep, and the resistant sandstones of the Mesaverde group form Coal Ridge, a prominent hogback. The dips of the northwestern limb are usually 20°–30°, but often steepen toward the Glenwood Springs syncline, due to the close folding of the latter.

Flattops arch.—This broad fold departs from the general northwest regional structural trend and branches from the White River Plateau arch in the vicinity of Baxter Mountain. The general trend is north through the Hunn's Peak area to the Flattops where it swings to the northwest (Fig. 1). The structure continues northwestward under the lava flows toward Axial.

Glenwood Canyon fold.—The structure between Glenwood Canyon and Baxter Mountain is complicated by a transverse fold trending N. 50°–60° E. It swings in a gentle arc to the northeast, from the Grand Hogback monocline, and dies out in the Carboniferous strata of Onion Ridge (Fig. 1). The structure is essentially a highly faulted gentle monocline. Previous workers have suggested the possibility of differential uplift between the White River Plateau and the Sawatch Range. This transverse structure probably represents such a zone.

Minor folds.—Minor folding is common in the Carboniferous rocks. The close folding of these rocks locally is probably a result of gypsum doming in response to tectonic pressures. Folding of this type was observed chiefly in the eastern part of the region south from Sweetwater Lake to Dotsero (Pl. 2, fig. 1).

Age of folding—Within the area no evidence was found of major folding throughout the Paleozoic or early Mesozoic, as formations of these eras show only disconformable contacts. However, a typical karst topography was developed on the upper Mississippian Leadville limestone surface, and additional regional work may uncover a slight angular unconformity at the base of the Pennsylvanian.

An angular unconformity may exist at the base of the early Eocene Wasatch formation since it dips less steeply than the older Cretaceous rocks. However, Hills (1891), Chamberlin (1919), and Vanderwilt (1937) have suggested a post-Bridger age (upper-middle Eocene) for the Grand Hogback monocline. Probably the folding of the Glenwood Springs region began during the late Cretaceous and continued through middle Eocene time.

FAULTS

General.—Faulting in the Glenwood Springs region is of the high-angle, gravity type characteristic of plateau areas. Stratigraphic throws vary from 50 to 1500 feet, and the faults range in length from a few hundred feet to 12 miles or more. Hinge, pivotal, block, and "horst and graben" types are common. Small reversals of movement have taken place along some normal faults, as shown by the drag of the beds along the fault plane.

For convenience, the term longitudinal faults is used for those parallel to the Grand Hogback monocline; those parallel to the Flattops arch are called oblique faults; and those parallel to the transverse folding are called transverse faults. This classification is employed because of the complexity of trends brought about by the swinging of the regional structure from north-south to east-west.

Longitudinal faults.—Faults parallel to the regional Grand Hogback monocline occur in the Canyon Creek area (T. 5 S., R. 90 W.) and northeast of Glenwood Spring (Pl. 3). In the former area the faults trend N. 70°–80° W. and are of two varieties. The more northerly are "horst and graben" types, and those to the south are closely spaced step faults on the steep monoclinal flexure (Pl. 2, fig. 2; Pl. 3, sec. A-A′). In

the Elk Creek region, several miles west of the area mapped, this zone of faulting appears to be continuous with a series of southwesterly dipping hinge faults of large throw. The faults trending N. 70°–80° W., northeast of Glenwood Springs, are in an area of complex structural trends. They dip northeast (Pl. 3, cross section B-B′) and are probably similar to the step faults of Canyon Creek. The largest shows a stratigraphic throw of 1300 feet.

Transverse faults.—The transverse faults strike N. 45°–80° E. and are parallel to, or closely associated with, the gentle Glenwood Canyon transverse folding. Typical faults are 5 or 6 miles long with stratigraphic throws of approximately 300 feet. A few are found in the Willow Peak area where not obscured by glacial till or soil cover, and several extend as far northeast as Onion Ridge. South of Baxter Mountain these faults are more numerous, strike nearly E.–W., and toward the west have the same bearing as the longitudinal faults of the Grand Hogback monocline. The general pattern is en echelon. The Quartzite Ridge horst is a topographic ridge more than a mile wide and 12 miles long (Pl. 3, sec. E–E′). The stratigraphic throw varies from 600 to 1300 feet. In the western part the block dips 10°–20° S. as the Grand Hogback monocline is approached.

Oblique faults.—Oblique faults of large displacement strike in a general N.–S. direction parallel to the trend of the Flattops arch. They occur at widely spaced intervals across the White River Plateau (Pl. 3). The strikes are curved and are generally less constant in direction than the longitudinal or transverse faults. The Bald Mountain fault immediately east of Bald Mountain is typical. The stratigraphic throw is 1200 feet, but the actual throw is somewhat less because of the drag of formations along the fault plane. The topographic expression of the Bald Mountain fault is more evident than that of other oblique faults. North of the Quartzite Ridge horst movement along the oblique faults was down on the east side; south of the horst it was down on the west side; and along the horst, the oblique faults are poorly developed and show little displacement. A pivotal or rotational movement has occurred.

Age of faulting.—Close association of faults and folds indicates that they were formed during the same period—that is, from late Cretaceous through middle Eocene. The oblique north-south faults usually offset the longitudinal and transverse faults and are somewhat younger.

RELATION TO REGIONAL STRUCTURE

General.—The White River Plateau is the lobate northwestern extension of the southern Rocky Mountains and is bounded on the north by the Green River Basin and on the west by the Uinta Basin. The Grand Hogback monoclinal structure is part of an extensive regional trend. Hills (1891) pointed out that the Grand Hogback monocline is continuous to the south with the Elk Mountains fault zone and to the northwest with a series of low anticlines extending to the Uinta Mountains (Fig. 1). The Castle Creek fault zone near Aspen, which is approximately parallel to the Elk Mountain fault zone, also changes to a monclinal flexure to the northwest and probably joins the Grand Hogback monocline near Glenwood Springs.

Diversity of structural trends.—The general northerly trend of the Rocky Mountain system swings in Utah, Wyoming, and northwestern Colorado to a distinctly east-

west trend. This may be the result of a change in the direction of the deforming force. However, previously existing structures or even conditions of sedimentation, as in the Uinta Mountains (Forrester, 1937), may have affected the final regional trends. In northwestern Colorado the northerly trend of the southern Rocky Mountains swings to the northwest and converges with the Unita Mountain trend.

At Glenwood Springs, where the Grand Hogback monocline changes abruptly to a westerly trend, its parallelism with the pre-Cambrian schistosity suggests control by the basement. On the other hand, the northerly trend of the Grand Hogback south from Glenwood Springs is parallel to the principal Laramide structures of the southern Rocky Mountains and cuts across the westerly pre-Cambrian trend lines. The Flattops arch and the oblique faults may well be continuous with this northerly trend. Thus the area just north of Glenwood Springs appears to be the locus of a complex cross structure.

Forces involved.—The fundamental forces which gave rise to the Rocky Mountains may have been vertical, horizontal, or both. Lee (1923, p. 290) suggested dominant vertical force followed by some lateral force developed by "local sag or settling of parts of the mountain mass following an uplift." On the other hand, advocates of horizontal force allow some vertical adjustments.

The structure of the Glenwood Springs region probably developed in response to differential vertical uplift of the White River Plateau relative to adjacent areas. The Grand Hogback monocline is evidence of such an uplift between the White River Plateau and the Uinta Basin. Chamberlin (1919) suggested that subsidence of the Uinta Basin might have been as important in developing the Grand Hogback monocline as upwarping on the Rocky Mountain side. The Glenwood Canyon fold and associated transverse faults mark another zone of differential uplift between the plateau and the northern Sawatch Mountains. The open folding, moderate crustal shortening, strong differential uplifting along monoclines and normal faults, and the extrusion of basaltic lava all indicate dominant vertical uplift of the White River Plateau.

Horizontal movements have developed thrusting in the Sawatch Range and along the Elk Creek and Castle Creek fault zones south of the area mapped; but no thrusting was observed in the Glenwood Springs region. However, the development of a joint system, local westward overturning of beds, and the formation of an anticline and syncline along the Grand Hogback monocline, together with the westward inclination of low anticlines northwest of Meeker and north of State Bridge, are all indicative of some compression.

Origin of local structures.—The dominant vertical orogenic forces probably gave rise to both north-south and east-west trends and developed torsion locally. The White River Plateau arch, the Elk Mountains, and the Sawatch Range represent regions of strong uplift; whereas the Uinta Basin and the Eagle Basin are downwarped (Fig. 4, A). Jointing, the Grand Hogback structure, and the associated longitudinal faults probably were formed in the order named during the early phases of uplift (Fig. 4, A). Continued differential movement between the regional positive and negative areas set up torsion which developed cross structures. An axis of torsion trending northwest could produce north-south tension and thus account for the

numerous en echelon east-west transverse faults (Fig. 4, B). Additional twisting and vertical movement along the axis of torsion may explain the differential uplift between the White River Plateau and the Sawatch Range, as expressed by the Glen-

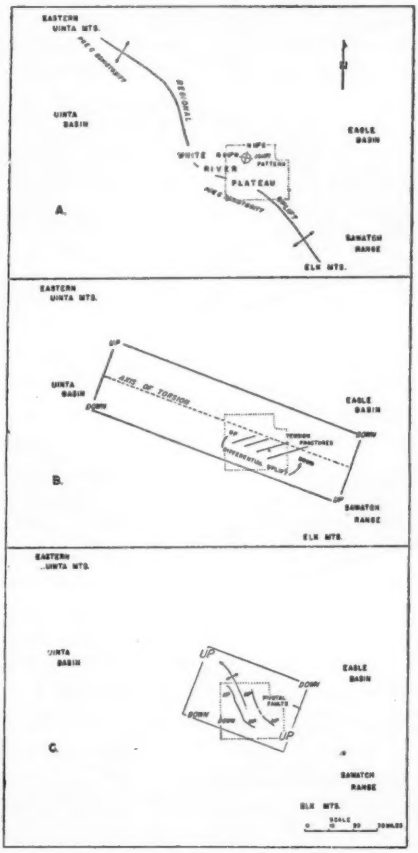

FIGURE 4.—*Origin of local structure*

A. Early formation of joints followed by the development of regional folding and longitudinal faulting controlled by basement structure.

B. Transverse tension and folding produced through torsion set up by relative vertical movement of regional positive and negative areas.

C. Oblique pivotal faulting and related folding during an advanced stage of torsion and vertical uplift.

wood Canyon fold and associated transverse faults (Fig. 4, B). Minor compression about this time would account for the westward overturning of beds along the Grand Hogback. During the final stages of torsion the full intensity of vertical uplift could produce the north-south oblique pivotal faults and the related Flattops arch (Fig. 4, C).

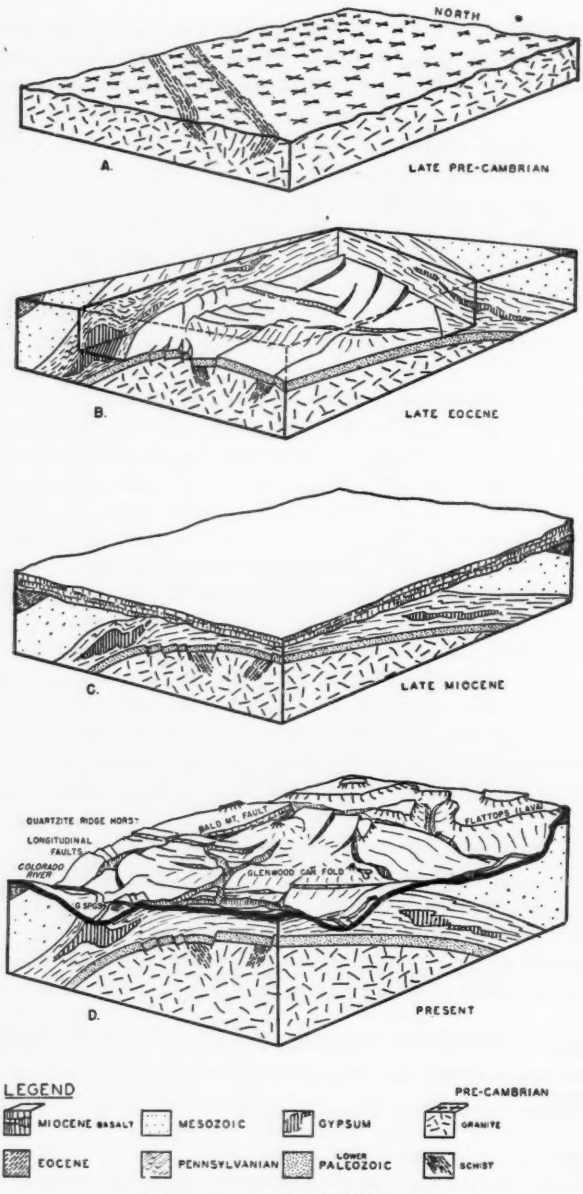

FIGURE 5.—*Local geologic history*

SUMMARY OF GEOLOGIC HISTORY

The northwest trend of the schistosity of Archean metamorphosed sediments intruded by pre-Cambrian granites may well be parallel to an ancient axis of folding

between the Glenwood Springs area and the Uinta Mountains (Fig. 5, A). Well-developed peneplanation and deep weathering are indicative of a long period of erosion prior to Paleozoic deposition.

Paleozoic sedimentation in central Colorado was interrupted by several recessions of the sea as evidenced by disconformable contacts. Although no evidence of Paleozoic deformation was found in the area studied, a slight angular unconformity at the base of the Pennsylvanian has been found elsewhere in Colorado.

Sedimentation of the Mesozoic era was largely continental. Reconnaissance in the area of these deposits showed no evidence of folding previous to the Laramide deformation. However, the Jurassic rocks in the Elk Mountain region to the south (Vanderwilt, 1937) rest upon a peneplaned surface of tilted Paleozoics. Vanderwilt recognizes a northwest structural trend for the pre-Jurassic movement and states (p. 82):

"This structure is parallel to that of the dominant trend of the more recent Rocky Mountains and is in accord with the general belief that the crustal disturbances of the later periods were probably controlled by the structure established much earlier."

The Eocene Wasatch formation is of continental origin, probably deposited in intermontane basins during the late Laramide uplift. There is some indication of an angular unconformity at the base, but many workers have noted that the Wasatch beds are usually as highly folded as the underlying Cretaceous Mesaverde group. Deformation probably began during the late Cretaceous and continued through middle Eocene time (Fig. 5, B).

A long period of erosion during the late Eocene and Oligocene reduced the mountain areas in Colorado to nearly level or gently undulating surfaces. Miocene uplift was reflected in renewed movement along fault planes and regional arching (Lovering, 1933). During the Miocene-Pliocene (?) another erosion surface was developed (Fig. 5, C). In the White River Plateau this peneplain is correlated with the Gilbert Peak erosion surface of the Uinta Mountains. Widespread volcanism during the Miocene or Pliocene is indicated by thick basaltic flows on this peneplain surface.

At the end of the Pliocene or during the early Pleistocene the White River Plateau was again uplifted probably in part along older fault planes but mainly by regional arching. The radiating pattern of stream valleys indicates doming in the Glenwood Springs region. This was followed by Quaternary lava flows and pyroclastics, some older and some younger than glaciation (Fig. 5, D). Pleistocene terrace gravels show no marked differential uplift. A small canyon cut in the glaciated valley northwest of Sweetwater Lake, and a lack of alluvium in the present canyons indicate continued or renewed uplift during recent time.

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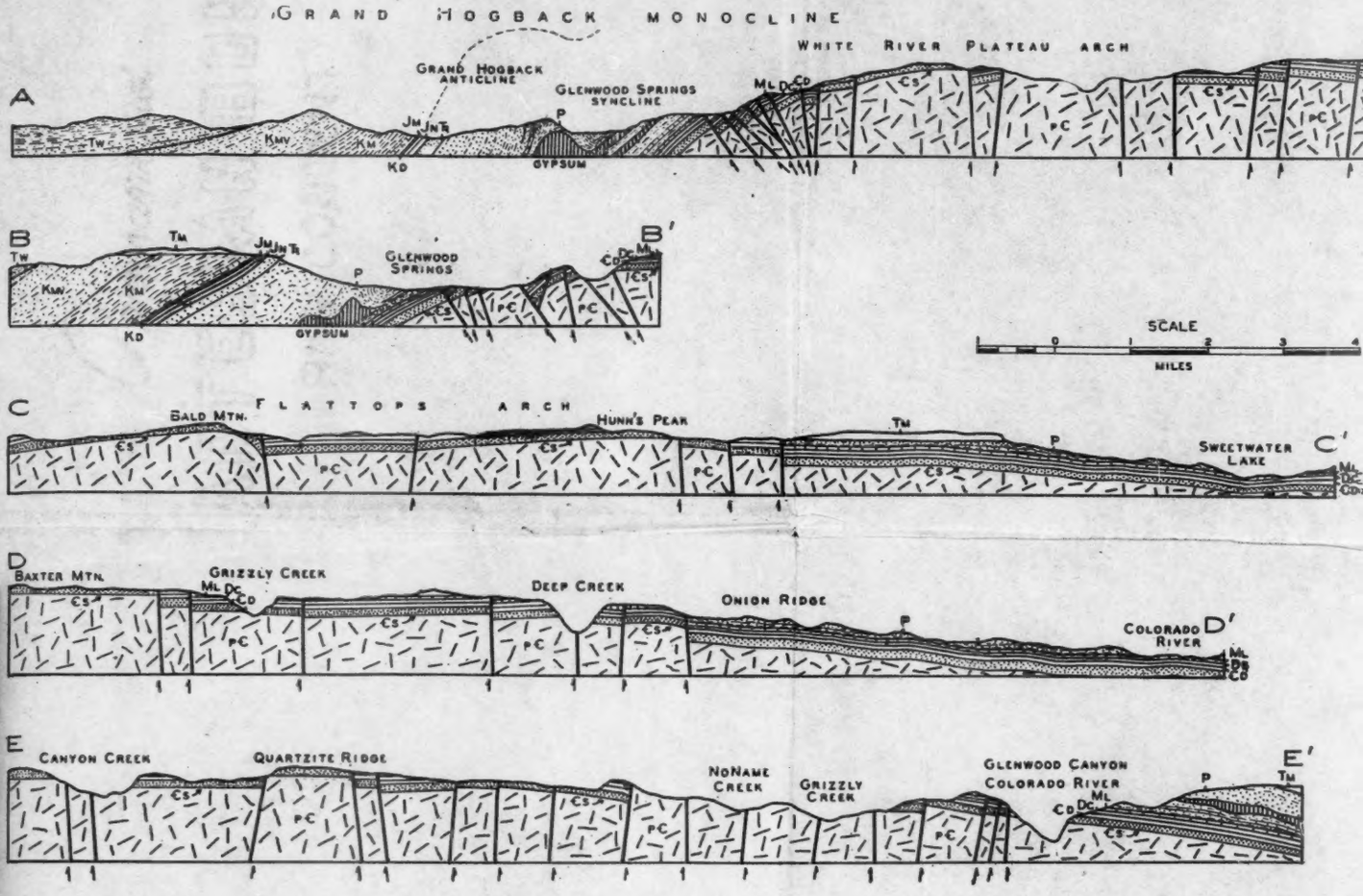
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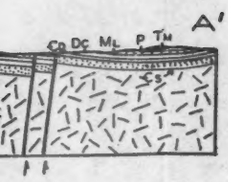

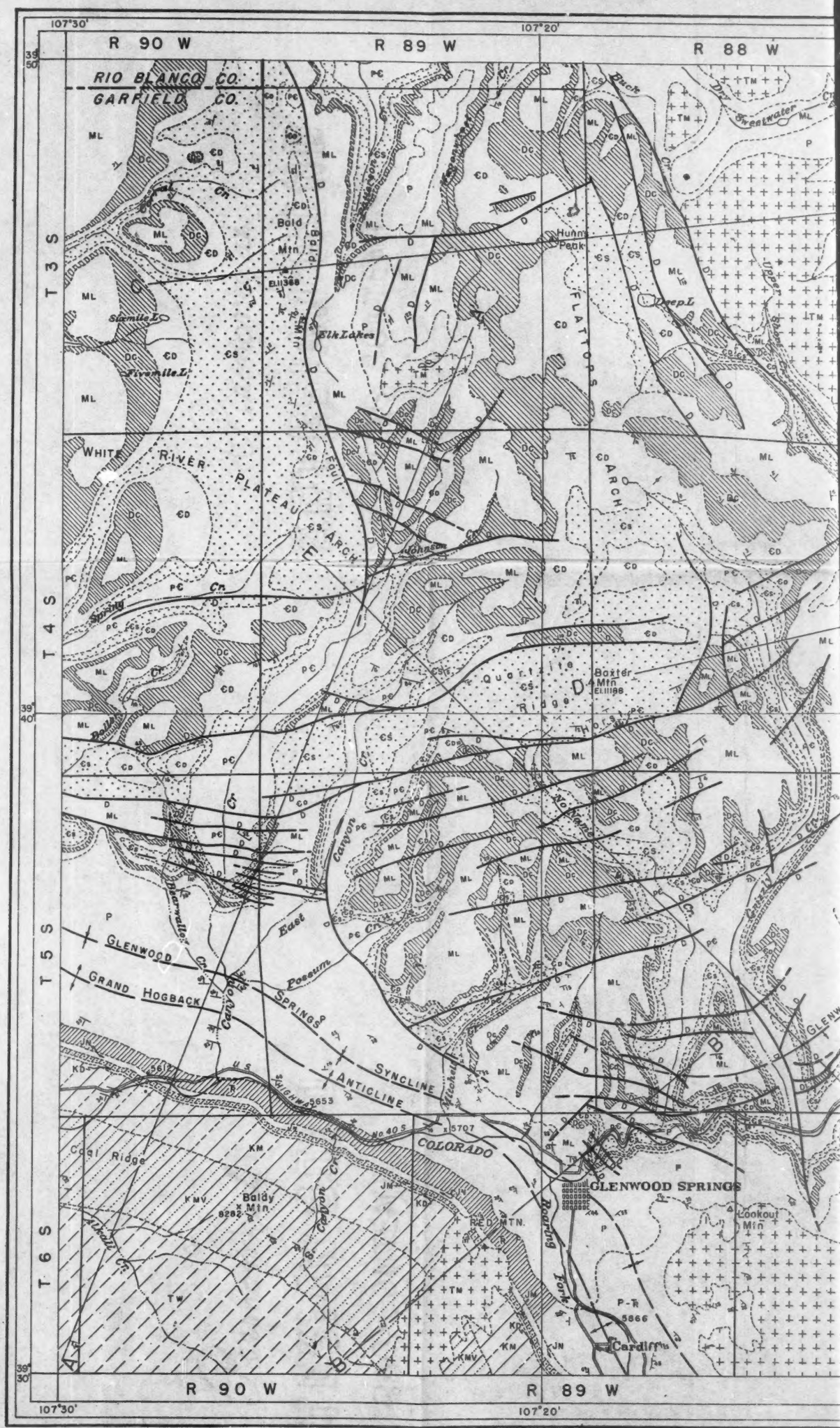
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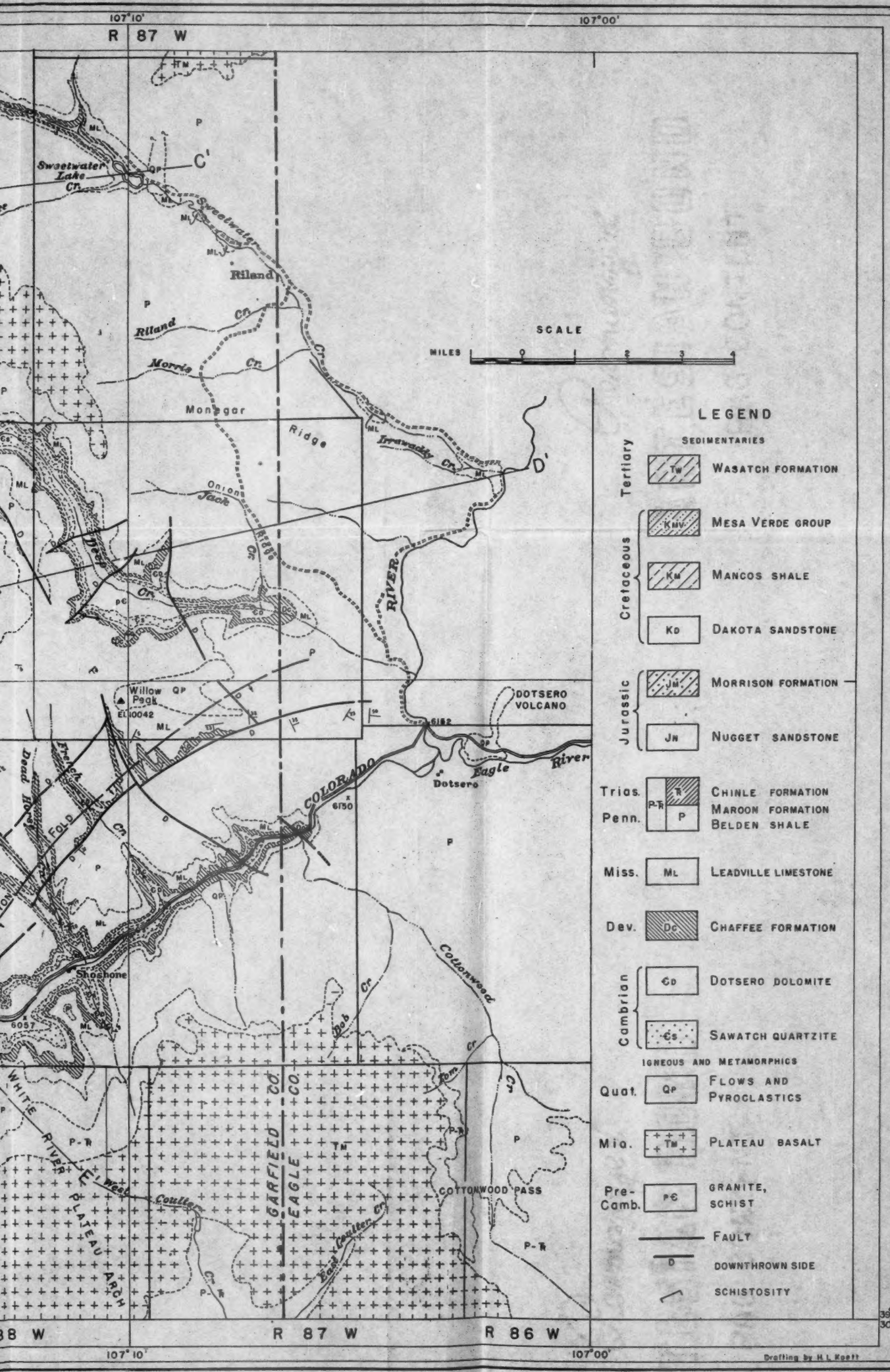
GEOLOGIC MAP AND STRUCTURE SECTIONS, NEAR GLENWOOD SPRINGS, COLORADO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Irrawaddy Cr.
Onion Jack Cr.
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Willow Peak
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DOTSERO VOLCANO
6182
Eagle River
Dotsero
COLORADO
6130
French Gulch
Deep River
Fold
Shoshone
6057
Cottonwood
Bob Cr.
Cr.
WHITE RIVER PLATEAU
GARFIELD CO.
EAGLE CO.
Coulter
East Coulter Cr.
COTTONWOOD PASS
SCALE
MILES
0 1 2 3 4
LEGEND
SEDIMENTARIES
Tertiary
TW WASATCH FORMATION
Cretaceous
KMV MESA VERDE GROUP
KM MANCOS SHALE
KD DAKOTA SANDSTONE
Jurassic
JM MORRISON FORMATION
JN NUGGET SANDSTONE
Trias. Penn.
P-R CHINLE FORMATION
MAROON FORMATION
P BELDEN SHALE
Miss.
ML LEADVILLE LIMESTONE
Dev.
DC CHAFFEE FORMATION
Cambrian
CD DOTSERO DOLOMITE
CS SAWATCH QUARTZITE
IGNEOUS AND METAMORPHICS
Quat.
QP FLOWS AND PYROCLASTICS
Mio.
TM PLATEAU BASALT
Pre-Camb.
PC GRANITE, SCHIST
FAULT
D DOWNTHROWN SIDE
SCHISTOSITY
Drafting by H. L. Keefe

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PERMIAN PEASE RIVER GROUP OF TEXAS

BY ROBERT ROTH

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ABSTRACT

The Pease River group is defined, and its surface expression at the type locality is described in detail. The correlation of the Pease River group with the Cherry Canyon formation of the Guadalupe Mountains is suggested.

INTRODUCTION

The Pease River group (new name):[1] Includes the San Angelo, Flowerpot, Blaine, and Dog Creek formations as exposed in Texas. Type locality South Fork of the Wichita River and Little Croton Creek in King and Knox counties, Texas (Fig. 1). Measured thickness 874.10 feet. Since the above formations form a natural group,

[1] The Pease River group was introduced by H. C. Fountain (North Texas Geological Society, Field trip road log, 1939), unpublished. Type locality Pease River in Hardeman and Cottle counties, Texas.

bounded by disconformities, it is believed that a name for this group might simplify the problems of nomenclature. However, the formations change facies so rapidly that any group name becomes a facies name. Examples: Pease River group, evaporite facies; El Reno, clastic facies; San Andres of the Sacramento Mountains,

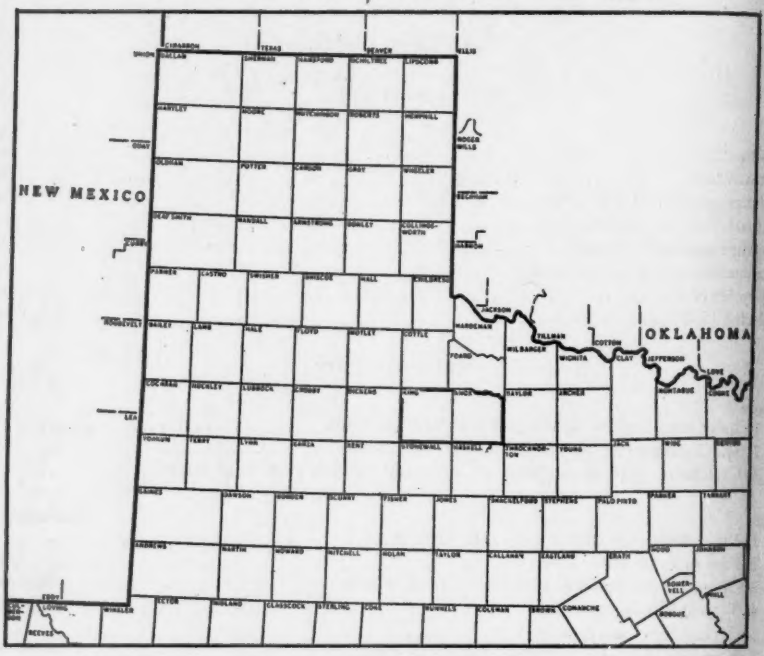

FIGURE 1.—*Index map locating King and Knox counties, Texas*

dolomite facies; Cherry Canyon formation, clastic and limestone facies. All appear to be variants of the Word.

In the past few years a number of wells have been drilled in King and Cottle counties, Texas, in search of petroleum. In each well that started on beds of Custer or younger age the Pease River group was several hundred feet thicker than had been estimated at the outcrop. Since the presence of salt beds had been suspected in the upper portion of the Pease River group the question arose as to whether the difference in thickness was due to the presence of salt at depth and its removal by solution at or near the surface, or whether a part of the difference was due to the presence of beds not previously recognized on the outcrop. It was thought that detailed measurement of the section exposed along the bed of the Pease River where solution would be at a minimum might aid toward finding the proper answer. General reconnaissance and detailed mapping of the group have demonstrated that only along the beds of major streams is there a relatively complete section. On the divides the section is greatly condensed due to solution.

FIGURE 1.
Wavy line indicates contact between Custer and Pease River group. Bed number 211 is 3 feet thick. Arrow to left indicates cedars on mounds. Location: southeast part of section 4, Sam Lazarus survey. Block 3. King County, Texas.

FIGURE 2.
Wavy line indicates contact between Clear Fork and Pease River groups. Bench below arrow is 2 feet thick and consists of anhydrite and gypsum. This bed becomes 20 feet thick in the immediate subsurface. Location same as Figure 1 of Plate 2.

UPPER AND LOWER CONTACTS OF PEASE RIVER GROUP

FIGURE 1. BASE OF SAN ANGELO SHOWING CHANNELING
X is area shown in Figure 2. Location: southeast ¼ section 472, block A., H. & T. C. R. R. Co., survey Hardeman County, Texas

FIGURE 2. DETAIL OF FIGURE 1
Note inch marks on hammer handle. Lens is a shale conglomerate with pebbles up to one inch in diameter. X marks same bed in both figures.

BASE OF PEASE RIVER GROUP

A preliminary examination of the terrain adjacent to the Pease River both on the ground and from aerial photographs indicated the advisability of finding some other area more easily accessible and one which would yield better exposures. About 40 miles south of the Pease River is the South Fork of the Wichita River in King County. The bed of this river is accessible by road from the south especially for the upper two-thirds of the Pease River group. The lower third of the group is well exposed on Little Croton Creek in the southeast corner of King County, 7 miles south of the South Fork of the Wichita River. Since all the main divisions of the group may be traced between the rivers it is believed that the general relations at the type locality are essentially the same as on the Pease River. All numbers appearing on the plates refer to bed numbers in the measured sections.

SOLUTION OF SALT AND ANHYDRITE

The solution of certain beds makes it impossible to measure exactly the interval between beds, and as a result detailed structure maps are liable to error. Highly erratic dips are usually present and in the main conform to the topography. Saline springs are common and were known to the early settlers, who were able to supply all domestic needs for salt by merely raking it out of the natural bittern pans. Many of the intermittent streams in the general area are known by such names as Croton or Salt Fork, indicating the general presence of salt. In the Pease River group there are also clay pseudomorphs after salt, and the dolomites in the upper Dog Creek formation contain many salt casts filled with a claylike foreign substance.

The Service Laboratory of the Humble Oil and Refining Company, Houston, Texas, has made the following analyses: springs in the South Fork of the Wichita River, elevation 1606 feet, and a water well drilled close to these springs located 1320 feet from the east line and 1490 feet from the south line of section 101, block A., John B. Rector survey, elevation 1776 feet (Fig. 2). They may be compared as follows in parts per million.

Sodium	11,200	1980
Calcium	1436	1274
Magnesium	187	29
Chloride	18,050	3360
Sulphate	3000	2650
Bicarbonate	140	140
Total	34,013	9433
Total solids (180°C.)	38,630	10,415

The water in the well stands at an elevation of 1616 feet. These analyses indicated an abundance of salt very near the surface exposure of the Dog Creek formation. It is also apparent that a great amount of anhydrite is going into solution (Pl. 8, fig. 2). A well drilled by the Humble Oil and Refining Company known as the Matador B-2, 43 miles northwest of the town of Guthrie, furnished exceptionally good samples because during the drilling of the upper part of the hole a salt-saturated drilling fluid was used which did not dissolve the salt beds. In this well the Pease River group is 1280 feet thick; of this, 220 feet of salt could be identified, and probably an equal amount was dissolved in the drilling fluid when not salt-saturated.

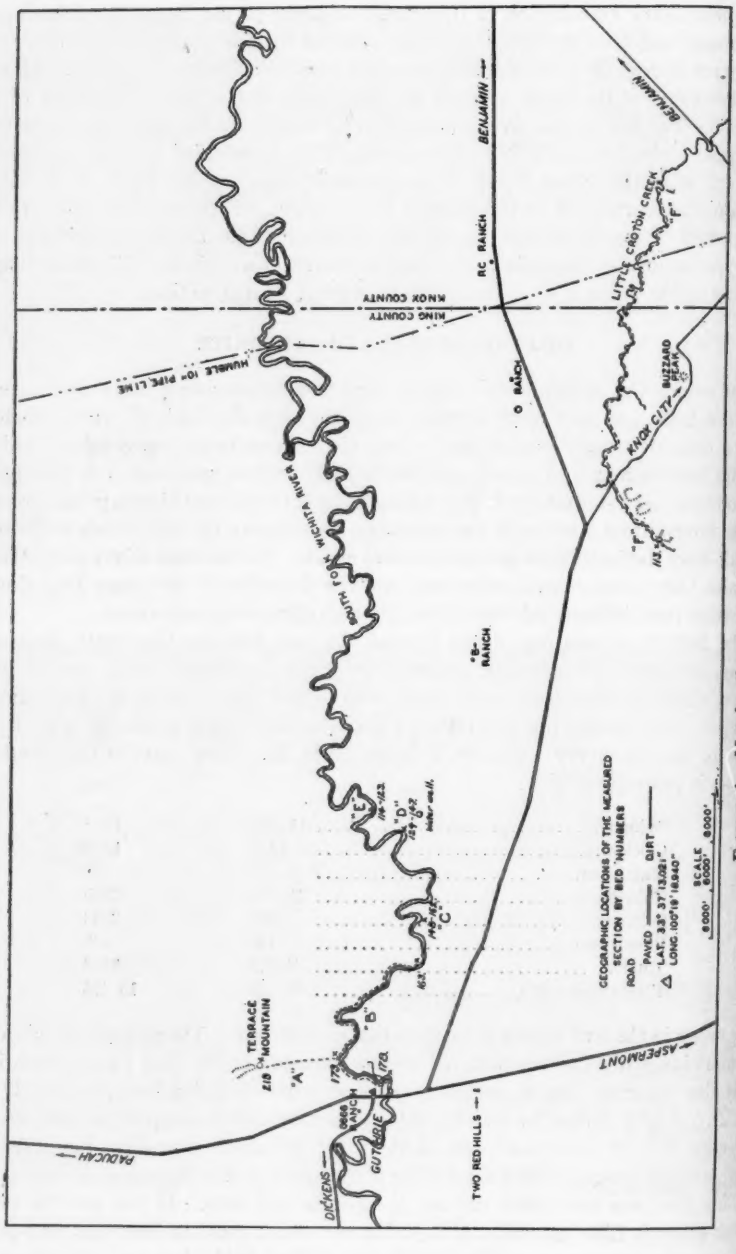

FIGURE 1.—*Map locating measured sections with bed numbers*

Evidence of the solution of anhydrite is common (Pl. 6, fig. 2; Pl. 7; Pl. 8), and the secondary deposition of calcium sulphate as gypsum, selenite, and satin spar is widespread (Pl. 3, fig. 1). The effect of solution and secondary deposition makes intercounty correlation difficult.

Usually the dolomites in the Pease River group are very fossiliferous and have been studied in great detail (Clifton, 1942; 1944a). These dolomites may be mapped over extensive areas. Most of them are locally oölitic; others are conglomeratic.

PALEONTOLOGIC CORRELATION

About 40 species have been reported (Clifton, 1944a) from the Pease River group. Some of the species, notably Cephalopods, are considered excellent regional markers, but unfortunately their evidence is conflicting. *Perrinites hilli* is considered a type fossil of the Leonard, while *Pseudogastrioceras roadense* and *Agathiceras girtyi* are believed to be of Guadalupe age. Paleontologists who favor the latter correlation hold that *Perrinites* is a carryover. Attention is called to the fact that where *Perrinites* has been found in the Pease River group it is almost invariably associated with an oölitic, conglomeratic, pelecypod coquina. The individual pebbles are an inch or more in diameter, thus indicating a near-shore environment. Where present the remains of these organisms are so numerous that food must have been plentiful, or else the organisms died in an environment which lacked sufficient food. Furthermore *Perrinites* has been found in thin beds of anhydrite; the deposition of the latter is not considered to have been in an environment of normal marine conditions. On the other hand the same conditions apply to those fossils whose evidence suggests an early Gaudalupian age as these fossils are associated with *Perrinites*. No fusulinids have been found.

The correlation chart (Fig. 3) places the Pease River group in the Cherry Canyon formation. Other correlations place the group in the Leonard (Roth, 1942). Both correlation charts have many controversial points of a lithologic nature. Since a Permian fauna has been recognized in the Quartermaster (Roth *et al*, 1941) its equivalence to the Dewey Lake appears established as recent drilling between Lubbock and Amarillo proves the equivalence of the Alibates and Rustler dolomites and anhydrites. The Brushy Canyon formation is a faunal blank except for the *Parafusulina rothi* assemblage, hence its regional extent is unknown.

On May 8, 1945, the writer accompanied Mr. John W. Skinner, of the Humble Oil and Refining Company, Midland, Texas, on a detailed investigation of the San Andres as exposed in the northern part of the Guadalupe Mountains and southern Sacramento Mountains. The section examined is exposed on the scarp west of B. M. 6090 feet, center of section 3, T. 24 S., R. 20 E., Otero County, New Mexico. About 1000 feet of San Andres is exposed above the Yeso gypsum. Mr. Skinner identified the fusulinids in the following estimated intervals from the top of the scrap down: 300–500 feet, dark cherty cliff-forming dolomite *Parafusulina rothi, P. maleyi, P. deliciasensis*, doubtful *P. lineata* and *P. sellardsi*; 800–900 feet, dark cherty limestones and dolomites downfaulted, to some extent, *Parafusulina sellardsi*, and

P. rothi. The presence of these fossils indicates a post-Leonard age for at least 800 feet of the San Andres of the Guadalupe and Sacramento mountains.

The San Andres in which the above fossils were found may be traced in the subsurface from west to east across the Permian basin into the Pease River group.

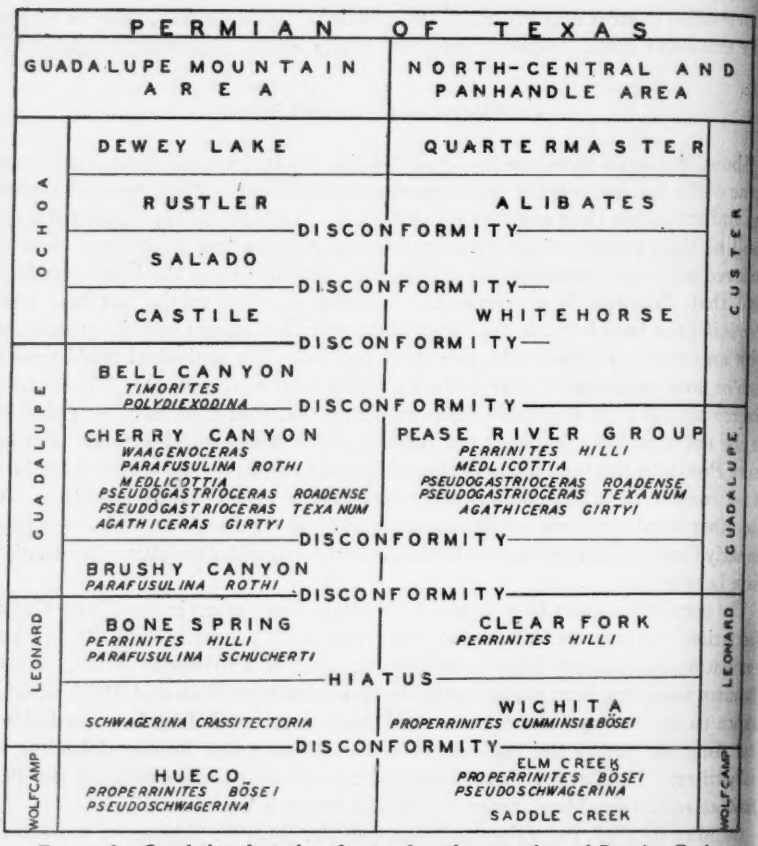

FIGURE 3.—*Correlation chart of northeast and southwest portions of Permian Basin*

DETAILED MEASURED SECTIONS

All fossiliferous horizons are noted in the following section; also all beds recognized on the areal geologic map of King County (County Geologic map, 1930) are indicated by the symbol used on the map. Correlations have been changed in many cases due to later information obtained from regional mapping.

Measured section A, starts in the center of the J. T. Williams survey, abstract 294, thence north to the top of Terrace Mountain located in the southeast part of section 4, block 3, Sam Lazarus survey, King County, Texas.

FIGURE 1. SELENITE VEINING IN GRITTY, BASAL FLOWER-POT
Bed number 20. Location: Little Croton Creek, King County, Texas.

FIGURE 2. CROSS-BEDDING IN SAN ANGELO
Bed number 14–18. Location: Same as above.

CHARACTERISTIC LITHOLOGY OF LOWER PEASE RIVER GROUP

FIGURE 1. TYPICAL EXPOSURE OF PEASE RIVER GROUP
Weak character of ash bed 127 is indicated. Location: Section 101, Block A., John B. Rector Survey. King County, Texas.

FIGURE 2. LOESS LIKE MATERIAL CAPPING BED ROCK
Skull and vertebrae of *Bison occidentalis* found in this material about 3 feet below surface not shown in figure. Arrow indicates contact. Location: Little Croton Creek, King County, Texas.

TYPICAL LITHOLOGIC EXPOSURES

CUSTER

WHITEHORSE GROUP, BEDS 215–219.

219	Light-gray, salmon-pink, white laminated anhydrite. Bench-forming....	4.67	

Childress dolomite, bed 218.

(Designated Db3 on 2–30)

Bed number		Thickness (Feet)	
218	Crinkled laminated very light-pink-buff dolomite.....	0.33	
217	Leached coarse orange-colored polished sandstone with gypsum cement and large frosted sand grains. Anhydrite and gypsum.....	2.50	
216	Orange-colored polished sandstone.....	8.00	
215	Fine leached orange-colored polished sandstone with a few large frosted sand grains.....	1.00	
	Total thickness.....		16.50

DISCONFORMITY

PEASE RIVER GROUP

Beds 10–214.

DOG CREEK FORMATION, BEDS 168–214.

214	Red-brown shale, selenite veins.....	18.00
213	Gypsum and green-gray shale with half-inch bed of very fine light-gray angular sandstone.....	1.67
212	Red-brown shale, selenite veining.....	5.00

Wagon Yard gypsum beds 208–211.

Locally cut out by disconformity above.

(Designated Dc., Royston on 2–30)

211	Light-gray gypsum and dense anhydrite. Bench-forming. Where measured, 3 feet thick, but usually 10 feet thick. Locally contains leached polished sandstone and large frosted sand grains (Pl. 1, fig. 1)	10.00

Beds 208–210 very local and not present where section was measured.

210	Porous oölitic buff dolomite.....	2.08
209	Laminated ripple-marked very light-gray dolomite, full of vugs filled with anhydrite.....	1.00
208	Dense laminated light-gray dolomite. Salt pseudomorphs. *Pleurophorus albequus*.....	0.50
207	Red-brown shale with a mass of selenite veins, green-gray shale at top....	24.00
206	Dense light-gray dolomite with a pale-green cast.....	0.17
205	Red-brown shale with a mass of selenite veins.....	18.00
204	Dense light-gray dolomite with a pale-green cast.....	0.25
203	Red-brown shale, selenite veins. One 4-inch bed of gypsum 5 feet above base (Pl. 5, fig. 1).....	6.67
202	Laminated light-gray gypsum and anhydrite. Bench-forming.....	5.00
201	Green-gray shale.....	5.00
200	Red-brown shale, selenite veining.....	5.00
199	Green-gray shale with three thin beds of gypsum.....	1.67
198	Red-brown shale, selenite veining.....	10.33
197	Gypsum.....	.50
196	Red-brown shale, selenite veining.....	5.00
195	Green-gray shale with selenite and gypsum, also a 1-inch bed of light-gray dolomite.....	1.17
194	Red-brown shale, selenite veining.....	5.00
193	Dense light-gray dolomite, green cast. Shaly.....	.17
192	Red-brown shale, selenite veining.....	5.17
191	Laminated red-brown anhydrite.....	3.00

Bed number		Thickness (Feet)
190	Coarsely oölitic red-pink to buff or light-gray dolomite locally conglomeratic. Thin beds of pelecypod coquina. *Pseudorthoceras splendens, Schizodus oklahomensis, Perrinites hilli, Edmondia rotunda.* The 6666 ranch headquarters rests upon this bed. (Designated Dd., Childress on 2–30)	2.50
189	Green-gray and some red-brown shale	15.00
188	Light-gray laminated anhydrite	4.00
187	Red-brown shale, probably some anhydrite above dolomite	5.17
186	Laminated light-gray-buff dolomite, green cast. Many vugs in upper half. (Designated Dd 1, on 2–30)	1.67
185	Red-brown and green-gray shale. Upper three-fourths is green-gray	5.00
184	Light-gray laminated anhydrite	6.00
183	Light-gray laminated oölitic dolomite. Pelecypods. This bed is the Aspermont dolomite, also the dolomite at Croton Falls which is very fossiliferous. (Designated De., on 2–30)	2.00
182	Red-brown shale with green-gray shale at top	15.50
181	Laminated light-gray anhydrite	5.17
180	Red-brown shale with green-gray shale at top. Gypsum shells	7.00
179	Light-gray gypsum and anhydrite. Some is nodular	8.33

Measured section B, starts in the center of section 2, B. S. & F. survey, thence west to the center of section 1, B. B. B. & C. survey.

Guthrie dolomite, beds 172–178.

(Designated Df., Guthrie on 2–30)

178	Very light-buff calcareous dolomite with vugs of anhydrite	1.83
177	Very light-buff calcareous shaly dolomite. Abundant worm borings	1.42
176	Very porous tan to buff oölitic limestone, *Schizodus* coquina. This bed forms a rock crossing on the South Fork of the Wichita River, just east of the courthouse at Guthrie and is the top bed causing the 3-foot falls on the above river	1.17
175	Very light gray-buff porous oölitic dolomitic limestone, largely a coquina. *Schizodus oklahomensis, S. texanus*	1.17
174	Very soft spongy tan-buff oölitic calcareous dolomite. Largely a coquina of the above fossils	4.33
173	Spongy granular tan-buff oölitic dolomite and dense buff dolomite. The upper half of this bed is very porous	3.17
172	Blocky light-gray shale with green cast. Some dense buff dolomite	2.50
171	Green-gray shale	7.33
170	Red-brown shale	15.50

Mangum dolomite?, bed 169.

169	Dense light gray-buff dolomite with few pelecypods. Large vugs of anhydrite, salt casts (Pl. 7, fig. 2)	6.00
168	Green-gray and red-brown shale	5.75
	Total thickness of Dog Creek formation	261.86
	Of this total thickness 15.8% is anhydrite and gypsum; 11.2% magnesian limestone; and 73.0% fine clastics.	

Blaine Formation, Beds 109–167.

167	Rubbly gray gypsum and anhydrite	5.75

Shimer dolomite, bed 166.

166	Blocky buff dolomite. Some is light gray and shaly. Thirty-four inches above the base there is a 5-inch bed of fine gray-buff grits cemented with selenite. The basal 14 inches is a very lenticular gray-buff granular locally oölitic dolomite. *Myalina sp., Schizodus oklahomensis, S. texanus, Pleurophorus albequus, Murchisonia gouldii, Pseudorthoceras* sp., *Edmondia rotunda, Perrinites hilli, Titanoceras* sp., *Coelogasteroceras* sp	3.97

Bed number		Thickness (Feet)
165	Red-brown shale with green-gray shale at top. All contains a mass of selenite veins	10.00
164	Laminated dark-gray gypsum	1.17
163	Green-gray shale, selenite veins	1.17
162	Massive light-gray gypsum and anhydrite	6.00

South Fork of the Wichita River. Section measured C, in the southeast part of section 104, block A, John B. Rector survey, King County, Texas.

161	Very light-gray dolomitic coquina. *Schizodus oklahomensis, Pseudomonotis* sp	2.42
160	Green-gray shale with some red-brown shale, and a few thin gypsum shells	8.33
	Acme dolomite, beds 156–159.	
	(Designated Dg., on 2–30)	
159	Porous light-buff soft dolomitic limestone coquina. Pelecypod coquina	2.00
158	Dense light-buff dolomite	5.00
157	Dense buff dolomite, contains a few small anhydrite-filled vugs. Gypsum biscuits	4.17
156	Dense light-buff dolomite. *Schizodus* sp	3.50
155	Red-brown and green-gray shale with selenite veining. Orange-colored gypsum biscuits	5.00
154	Laminated white, gray, and red-brown anhydrite and gypsum. One 3-inch bed of dolomite in the middle	5.00
153	Red-brown and green-gray shale, selenite veining	2.92
152	Massive white and light-gray anhydrite and gypsum	12.00
151	Laminated dark-gray gypsum and anhydrite	2.50
150	Massive mostly white anhydrite and gypsum	3.50
	Cedartop dolomite, beds 147–149.	
	(Designated Dh., on 2–30)	
149	Light-buff dense dolomite. Many vugs filled with anhydrite (Pl. 5, fig. 2).	2.67
148	Light-gray-buff dolomite, large vugs filled with anhydrite	4.33

South Fork of Wichita River. Section measured D, in the southeast quarter of section 102, block A., John B. Rector survey, King County, Texas.

147	Dense blocky buff dolomite. Pelecypods in top 6 inches	2.67
146	Green-gray shale	1.17
145	Green-gray shale with some red-brown shale in lower part. Selenite veining	1.42
144	Red-brown shale, selenite veining. One 5-inch gypsum lens 17 inches above base	3.58
143	Laminated gray gypsum and anhydrite. Upper 9 inches shaly, lower 9 inches dense	1.50
142	Dark-gray shaly gypsum	.75
141	White anhydrite	.75
140	Dark-gray and some red-brown gypsum	.58
139	White anhydrite	.67
138	Laminated dark-gray gypsum	2.58
137	Red-brown and green-gray shale, selenite veining	2.50
136	Massive light-gray laminated gypsum and anhydrite	6.00
135	Cream to buff dolomitic limestone, oölitic in places	1.00
134	Nodular and laminated gypsum	6.00
133	Green-gray shale	.83
132	Red-brown shale	2.67
131	White gypsum and anhydrite	1.00
130	Red-brown shale with veins of selenite	1.17
129	Gypsum and red-brown shale	3.00
128	Laminated dark-gray gypsum	1.92

Bed number		Thickness (Feet)
127	Very thin-bedded light-buff volcanic ash cemented with magnesian limestone. Very soft and only observable in fresh exposures (Pl. 4, fig. 1; Pl. 6, fig. 2)	5.00

South Fork of Wichita River. Section measured E, in northeast quarter of section 101, block A, John B. Rector survey, King County, Texas.

126	Green-gray shale	.50
125	Green-gray shale with purple cast	.83
124	Blue-green shale	2.33
123	Red-brown shale with several gypsum shells. Selenite veining	22.17
122	Laminated crystalline nodular gray gypsum; lower part has red-brown cast	4.17
121	Green-gray shale with little red-brown shale at base	1.33
120	Nodular white gypsum with 4 inches of light-buff and tan-buff magnesian limestone, very local at base. Some small pelecypods	2.67
119	Green-gray shale, laminated gypsum and selenite	1.25
118	Light-gray anhydrite	1.25
117	Laminated shaly green-gray crinkled gypsum	3.17
116	Red-brown and green-gray shale with large selenite dikes	2.00
115	Platy earthy gypsum with red-brown shale	.67
114	Red-brown and green-gray shale	1.67

South Fork of Wichita River. Section measured F, on Little Croton Creek in section 101, block D, H. & T. C. R. R. Co. survey, Knox County, Texas. Thence west up creek to foot of hill in northeast part of Wm. E. Roberts survey, abstract 269, King County, Texas.

113	Massive light-gray gypsum and anhydrite	20.00

Medicine Lodge dolomite, beds 109–112.

(Designated Di., McCaulley on 2–30)

The McCaulley dolomite at the type locality is probably Cedartop in age.

112	Light-gray gypsum and oölitic buff dolomite	1.00
111	Coarsely oölitic calcareous buff dolomite	.50
110	Dense pink secondary limestone	.50
109	Porous granular buff dolomitic limestone coquina. Some is oölitic. *Pleurophorus* sp., *Schizodus* sp	.50
	Total thickness of Blaine formation	204.67
	Of this total thickness 44.0% is gypsum and anhydrite; 16.7% magnesian limestone; 39.3% fine clastics.	

Flower-pot Formation, Beds 20–108.

108	Red-brown and green-gray shale	8.00
107	Laminated dark-gray gypsum	1.33
106	Green-gray and red-brown shale, much selenite veining	2.50
105	Gray gypsum	1.17
104	Green-gray shale	1.50
103	Red-brown shale	1.25
102	Light-gray gypsum and anhydrite	2.17
101	Red-brown and green-gray shale	4.00
100	Laminated light-gray gypsum and anhydrite. Basal 3 inches weathers to an ocher color	6.00
99	Green-gray shale	2.33
98	Laminated dark-gray gypsum	1.17
97	Green-gray shale	.83
96	Laminated dark-gray gypsum	1.83
95	Some red-brown and green-gray shale, mostly selenite. Trace of light-gray dolomite	2.33
94	Dense gray gypsum	1.33
93	Red-brown selenite and shale	2.33
92	Dense laminated gray gypsum and anhydrite	1.17

FIGURE 1. CEDARS ON THREE FOOT MOUNDS
Detail of Figure 1 of Plate 1. Location: Same as Figure 1 of Plate 1.

FIGURE 2. ANHYDRITE BISCUITS IN CEDARTOP DOLOMITE
This is characteristic of most of the dolomites in the group. After the anhydrite has been lost due to solution the dolomite has a very rotten appearance and sometimes assumes a pisolitic aspect. Location: southeast of Section 104, Block A, John B. Rector survey, King County, Texas.

TYPICAL LITHOLOGIC EXPOSURES

FIGURE 1. TERRACE REMNANTS ON CUSTER
Number 3 is present epicycle of erosion; No. 1 is the older terrace, No. 2 the younger. Location: Section 195, H. & G. N. survey, Motley County, Texas.

FIGURE 2. TYPICAL CONDENSING OF INTERVAL
Note that part of section which may be measured with accuracy is from the river bed up to top of bed number 127. Location: Section 114, Block A, John B. Rector survey. King County, Texas.

Bed number		Thickness (Feet)
91	Green-gray shale and gypsum	.67
90	Massive nodular light-gray gypsum	3.67
89	Red-brown selenite and shale. Top 28 inches green-gray shale, also bottom 28 inches	6.83
88	Nodular earthy light-gray gypsum with distinctive 6-inch dark-gray gypsum bed at top	2.50
87	Green-gray shale with selenite and orange-yellow gypsum biscuits	4.67
86	Light-gray dense calcareous dolomite	.08
	Kiser gypsum and anhydrite, beds 71–85.	
85	Massive laminated light gray gypsum and anhydrite	5.00
84	Green-gray shale	.50
83	Nodular gypsum and green-gray shale	.83
82	Massive laminated light-gray gypsum and anhydrite	6.50
81	Green-gray shale	.33
80	Massive laminated light-gray gypsum and anhydrite	4.83
79	Green-gray shale and some red-brown shale. One 3-inch bed of light-gray calcareous dolomite 12 inches above the base	2.50
78	Light-gray gypsum and anhydrite	.67
77	Green-gray dolomitic shale	1.00
76	Crinkled light-gray gypsum	2.33
75	Green-gray shale with crinkled gypsum in lower 6 inches	1.17
74	Green-gray shale with selenite veins	1.50
73	Laminated and crinkled light-gray gypsum	.92
72	Green-gray shale	.50
71	Massive light gray gypsum and some anhydrite. Many caverns. Eight inches above the base there is a porous cream-colored oölitic dolomite. *Pleurophorus albequus, Schizodus* sp.	7.33
70	Green-gray and red-brown shale. Steel bridge on Little Croton Creek	2.42
69	Green-gray laminated dolomitic gypsum	1.17
68	Green-gray shale	.58
67	Green-gray gypsum. In 300 feet this bed becomes an earthy laminated gypsum resembling onyx	.58
66	Red-brown shale with tan gypsum biscuits in lower part	6.00
65	Nodular light-gray gypsum	1.33
64	Thin-bedded green-gray shale and some red-brown shale. Trace of dolomite	4.00
63	Calcareous porous gray and buff dolomite. Part of it is a coquina of small pelecypods. Some gypsum and trace of galena	.17
62	Laminated gray gypsum	1.00
61	Green-gray shale	.50
60	Laminated gray gypsum. Huge nodules a foot in diameter on top	.92
59	Gray shale with green cast, slightly gritty. Upper 8 inches is dolomitic	3.00
58	Green-gray shale	1.58
57	Red-brown shale	1.17
56	Nodular light-gray gypsum	1.33
55	Green-gray shale	.50
54	Nodular red-brown gypsum and shale	2.00
	Chaney gypsum and anhydrite, beds 43–53.	
53	Nodular light-gray gypsum	2.17
52	Red-brown and green shale	.83
51	Nodular massive light-gray gypsum (Pl. 8, fig. 1)	8.50
50	Oölitic gray-buff dolomite, contains some gypsum crystals. Ripple-marked and rain-pitted	.58
49	Red-brown and green-gray shale	1.00
48	Earthy red-brown gypsum	2.00
47	Light-gray nodular gypsum	2.67
46	Red-brown and orange-red shale with gray streaks in middle, selenite veining	2.50
45	Laminated nodular gray and maroon gypsum, may be conglomeratic	2.75
44	Red-brown shale not leached	2.08
43	Nodular and laminated light-gray gypsum	3.00
42	Red-brown shale	5.00

Bed number		Thickness (Feet)
41	Green-gray shale with gypsum biscuits in upper part. There are two gypsum beds in the middle of this interval which grade laterally through 1000 feet into two beds of oölitic gray-buff and light-gray dolomite containing worm borings and small pelecypods. The upper 8-inch dolomite is separated from the lower 4-inch dolomite by 12 inches of green-gray shale	10.00
40	Laminated gray gypsum	2.33
39	Red-brown shale, top 13 inches is green gray. Gypsum biscuits	2.50
38	Nodular light-gray gypsum	1.50
37	Red-brown shale, top 10 inches is green gray	4.00
36	Nodular earthy laminated gypsum	4.17
35	Red-brown shale, lower part has maroon cast. Green-gray shale at top. Six inches above the base there is a 6-inch bed of nodular tan gypsum	2.83
34	Laminated gray gypsum	6.00
33	Red-brown shale with several green-gray shale beds in upper half	10.33
32	Laminated light-gray cavernous gypsum (Pl. 7, fig. 1)	3.00
31	Red-brown and green-gray shale with six thin gypsum beds each approximately 6 inches thick (Pl. 4, fig. 2)	20.67
30	White gypsum and selenite, azurite	1.67
29	Green-gray shale in lower half, red-brown in upper half	2.33

Chalcocite dolomite, beds 22–28.

(Designated Dk., on 2–30)

Well exposed at the RC Ranch which rests upon this bed.
Knox County, Texas.

28	Light-gray dolomite containing chalcocite partially altered to malachite in orthorhombic crystals. Few small pelecypods. *Allorisma rothi, Pleurophorus albequus*	.33
27	Green-gray shale	1.17
26	Same as bed 28	.50
25	Green-gray shale with gypsum biscuits	1.17
24	Same as bed 28 plus some green-gray shale	1.00
23	Green-gray shale with gypsum biscuits	.67
22	Same as bed 28	.33
	Beds 22–28 are bench forming and vary greatly in thickness.	
21	Red-brown shale with some leached zones. Large anhydrite biscuits. Top 2 feet of the interval contains green-gray shale with anhydrite biscuits, very local in thickness. Second 10 feet above base contains green-gray grits and shale with selenite, all very cross-bedded. Top 10 feet contains red-brown shale with a 4-inch bed of light-gray-buff to green-gray dolomite. Some coquina and conglomerate	35.00
20	Gritty green-gray shale with selenite veins (Pl. 3, fig. 1)	6.00
	Total thickness of Flower-pot is	274.0
	Of this total thickness 34.9% is anhydrite and gypsum; 1.0% is magnesian limestone; and 64.1% is fine clastics.	

San Angelo Formation, Beds 10–19.

19	Coarse clay-ball conglomerate containing large pebbles of gypsum. Plant stems and bone fragments	1.00
18	Red-brown and leached cross-bedded grits. Much red-brown shale. Cross-bedding	7.00
17	Laminated grits and red-brown shale. Very cross-bedded. Much selenite and in the upper part there are gypsum biscuits. Bench former (Pl. 3, fig. 2)	27.00
16	Conglomeratic laminated gray cross-bedded sandstone and dolomitic grits with clay-ball conglomerates. Worm borings. Humble Oil & Refining Company's 10-inch pipe line and telephone to the Panhandle of Texas cross Little Croton Creek here	12.00
15	Red-brown shale with several gray streaks of grits. Channeling at top	19.00+
14	Soft laminated sandstone with some red-brown shale at base. Bench former	17.00
13	Massive dolomitic and calcareous subangular sandstone, weathers into rounded relief	7.00

FIGURE 1. TYPICAL DEVELOPMENT OF CAVERNS IN ANHYDRITE
Much of the surface drainage is carried off in this manner. The shale below is relatively impervious. Location: Little Croton Creek. King County, Texas.

FIGURE 2. AN EXAMPLE OF CONDENSED INTERVAL DUE TO SOLUTION OF ANHYDRITE
Thickness of beds: No. 166, 3.92 feet; 167, 5.75 feet; 168, 3.50 feet; 169, 6.00 feet. As a result the Mangum? No. 169 and Shimer No. 166 appear as one bed. Location: Section 2, B. S. & F., Survey. King County, Texas.

SOLUTION OF ANHYDRITE

FIGURE 1

Large blister developed in thin anhydrite bed due to hydration and resulting expansion. Bed number 51 is a massive anhydrite, the large block which has broken loose and rotated toward the observer thus showing the upper part which has expanded and become spongy due to hydration. Location: Little Croton Creek, King County, Texas.

FIGURE 2.

Characteristic solution of anhydrite where the run-off is very rapid. Note six inch scale. Location: as above.

WEATHERING OF ANHYDRITE

Bed number		Thickness (Feet)	
12	Soft laminated cross-bedded sandstone	7.00	
11	Laminated cross-bedded dolomitic fine sandstone and red-brown shale. Selenite and worm borings. Bench former	20.67	
10	Laminated cross-bedded ripple-marked sandstone containing some small frosted sand grains, also several feet of green-gray shale. Plant stems and chalcocite pseudomorphs after wood. Chalcocite also occurs as reniform masses frequently coated with malachite or as orthorhombic crystals, but usually occurs as finely disseminated in sandstone and gypsum (Pl. 1, fig. 2; Pl. 2)	15.50	
	Total thickness of the San Angelo formation is. Of this total thickness 14.2% is fine clastics; and 85.8% is sandstone.		133.17
	DISCONFORMITY		
	CLEAR FORK GROUP, BEDS 1–9.		
9	Green-gray shale	3.00	
8	Red-brown shale with some gypsum biscuits	14.00	
7	Green-gray and red-brown shale, gypsum biscuits in upper part	2.00	
6	Red-brown shale, polka-dotted. Selenite veins	10.33	
5	Red-brown and green-gray shale with selenite veining	2.00	
4a	Six inches of laminated dolomitic grits with vugs filled with anhydrite. Conglomeratic	.50	
4	Green-gray shale at top and bottom with 10 inches of red-brown shale in the middle. White, maroon, and orange-colored gypsum biscuits	2.00	
3	Red-brown shale, polka-dotted, some gypsum biscuits	6.50	
2	Green-gray shale with gypsum biscuits	1.00	
1	Red-brown shale, polka-dotted	2.00	
	Total thickness of Clear Fork measured is		43.33

COMMENTS ON MEASURED SECTIONS

Most of the green-gray shales were deposited as red-brown shales. The change in color is due to the reduction of the iron compounds. The Aspermont dolomite, 41 feet above the Guthrie dolomite at Aspermont, Stonewall County, Texas, forms the very fossiliferous magnesian limestone at the falls on Croton Creek also in Stonewall County. Northward the Guthrie dolomite underlies the town of Kirkland in Childress County, Texas. Certain beds, notably number 127, contain appreciable volcanic ash. Salt occurs at numerous horizons either as beds or as impregnating material especially in the Dog Creek formation evidenced by the presence of salt springs and as casts. Anhydrite is rapidly being dissolved by meteoric waters. Its absence is indicated by caverns, sinkholes, and condensed intervals. The contact between the San Angelo and the Flower-pot is transitional. *Perrinites hilli* occurs through an interval of at least 150 feet, principally in the Dog Creek formation. The total thickness of the Pease River group as measured (874.10 feet) indicates the presence of beds which have been overlooked in the various condensed intervals measured. This thickness is very near that found in the various wells drilled in the area.

EPICYCLES OF EROSION

Owing to the general lack of vegetation the llanos of western Texas afford an ideal setting in which the effects of sheet erosion may be studied. The comparatively steep gradients of the side drainage of all the major streams have destroyed all but a

very few terraces. In King County and the adjacent areas only one place is known where more than one terrace may be observed. This area is south of the first concrete bridge on U. S. highway 62, 70 connecting Paducah with Matador, 8000 feet west of the west abutment of the bridge over the South Pease River—center of section 195, H. & G. N. R. R. Co. survey, Motley County, Texas (Pl. 6, fig. 1). The material composing the older terrace is a buff to buff-brown sandy silt containing a few scattered pebbles of dolomite and anhydrite which are several inches in diameter; one large isolated siliceous boulder 8 inches in diameter was found. This terrace material weathers into cliffs with vertical cracks, as in loess. The terrace is about 20 feet high. The younger terrace is composed of materials similar to number 1, but more conglomeratic; pebbles up to 3 inches in diameter are common. In most places it is quite cross-bedded and about 10 feet high (Pl. 4, fig. 2).

The present epicycle has gullied extensively, even beyond the older terrace and onto the ancient rolling plain. An effort has been made to date this last phase of activity. It was noted that on certain shale flats *Juniperus mexicana* (Mountain Cedar) and *Prosopis juliflora* (Mesquite) were growing on mounds of shale remnants 1–3 feet in height (Pl. 5, fig. 1; Pl. 1, fig. 1). Obviously the shale surrounding the plants has been removed during their life. Since the age of the cedars may be determined approximately by counting the annular rings, the approximate age of the mound can be ascertained. Two cedars presented the following information: (1) height of mound 2 feet, birth of cedar *circa* 1793; (2) height of mound 3 feet, birth of cedar *circa* 1794. Since there was a foot difference in the height of the mounds and since the two trees were from the same place the conclusion is that the present epicycle started much later than the birth of the trees. Early settlers agree that the mesquite has spread over the area in the last 50 to 60 years. Two mesquites which grew near the cedars were examined. The information obtained was not very exact because of the difficulty in counting the annular rings. The results are therefore approximate within a few years: (1) height of mound 1 foot, birth of mesquite *circa* 1924; (2) height of mound 1 foot, birth of mesquite *circa* 1929. This indicates a foot of erosion in the last 15–20 years. A study of the annular rings of the cedars does not indicate any difference in the amount of precipitation from 1924 to 1944 when compared with 1904 to 1924. The conclusion is that about 1 foot of sediment has been removed during every 20 years or that the present epicycle started about 60 years ago. This date coincides with the time at which intensive cattle grazing was initiated in this part of Texas.

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KNOXVILLE SERIES IN THE CALIFORNIA MESOZOIC

BY F. M. ANDERSON*

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ABSTRACT

The Knoxville series, the latest West Coast Jurassic, is best developed and best preserved and exposed in its type area on the west border of the Sacramento Valley, in Tehama County. It consists of deltaic deposits having a maximum thickness of 16,300 feet and an average thickness of 11,600 feet. It forms three major stratigraphic groups, each characterized lithologically and stocked with appropriate faunas of marine invertebrates, which occupy a chronological span from early-middle Portlandian to latest Tithonian time of the European scale. In part the series crops out at intervals on the west border of the Great Valley for nearly 300 miles. Outside this valley it is traceable southward to the Santa Ynez Range and northward to partly correlative deposits in western Oregon, Washington, British Columbia, and southern Alaska. The Knoxville series contrasts strongly in composition, structures,

faunistic features, and geologic history with the next older, the Franciscan and Mariposa groups, both of which occupy distinct geographical areas.

Historically the Knoxville epoch is a distinct chronological unit between the Nevadan orogeny at the close of the Mariposa-Mount Jura epoch and the earliest Cretaceous epoch, the deposits of which occupy distinct areas on the West Coast. It includes the earliest marine deposits laid down in the Great Valley trough and in other troughs developed farther north by the Nevadan orogeny. Correlative deposits occur in many parts of the world—Cutch, southwest India; the Lower Volga basin, Russia; in western Germany; at Speeton, England; and in Japan.

INTRODUCTION AND ACKNOWLEDGMENTS

In the early work of the Whitney Geological Survey in California (1865; 1869) little was known of the Knoxville series. This series was first brought to light by the U. S. Geological Survey, beginning with the work of G. F. Becker and C. A. White (1884–1888), and by others of the Survey who had worked in the Coast Ranges.

The present study begins with the work of Becker and White (1884–1888), followed by the important work of Diller and Stanton (1892–1908), and by others of the Geological Survey in the Coast Ranges. Becker and White (1888) first directed attention to the important marine deposits that preceded Cretaceous time, not well understood by Whitney and Gabb (1869, Preface), but discussed by Becker (1888) under the name "Knoxville series" (or Knoxville group).

In view of the stratigraphical importance of this sequence, and of its natural divisions, it appears better to give it the higher rank, and accordingly it is here discussed under the name Knoxville series, as was done by the writer in his preliminary account (1933). As no trustworthy account or correlation of these deposits could be made without a paleontological basis, many fossil invertebrates have been gathered from all parts of the series and have been placed in the collections of the California Academy of Sciences, San Francisco.

The author wishes to acknowledge here the helpful co-operation and valuable aid given by his associates, already mentioned in part in his preliminary account (1933). Of much value was the early co-operation of O. P. Jenkins of the State Division of Mines and of W. W. Bradley and many others. Especially appreciated is the co-operative aid of the Texas Company, and its personnel, namely, the late Ralph D. Reed, and A. I. Gregerson and R. W. Burger. The carefully made pace traverses and notes, and finally the standard sections worked out with engineering technique by these men, have been of the greatest aid in the descriptions and the illustrations of the sections along the courses of Redbank and McCarthy creeks, Tehama County. Later Gregerson and Burger led the writer over the entire section on Redbank Creek, pointing out many of its important features shown in their illustrations. Later work by the writer along McCarthy Creek and other sections was greatly aided by Thomas Stipp, H. O. Jenkins, Robert Rist, and by others, not all of whom can be mentioned here. Joseph A. Taff and C. M. Cross, of the Associated Oil Company, participated in various arduous traverses in the vicinity of Elder Creek and of Toms Creek, at the base of the Knoxville series. And finally, thanks and appreciation are due Dr. A. C. Lawson for encouragement, kindly advice, and co-operation, extending over many years, beyond the beginning of this work.

FORELAND OF KLAMATHONIA

The name Klamathonia was proposed by the writer (1938) for the Mesozoic land areas that are now largely occupied by the Klamath Mountains in northern California and southwestern Oregon. Its areas extended from the latitude of Clear Lake, California, to that of the Umpqua and Coquille rivers in southwest Oregon. This ancient land constituted an irregular, broadly triangular mountainous block, which on the west faced the Pacific Ocean but on the east thrust its apex against the broad continental border. The emergence of this mountain block above the sea began in early Paleozoic time, although its earlier history is veiled or only dimly outlined in its older terrains, dating far back of Devonian time. In its more prominent mountain ranges (Yolla Bolly, Trinity Alps, Lassic Peak, Scott, Siskiyou) there are ancient schists, gneisses, quartzites, and siliceous, thin-bedded assemblages that antedate Devonian time. Prominent among these older rock types are the Salmon and Abrams schists described by Hinds (1935) and other sedimentary, eruptive, and metamorphic types, that range in age from "pre-Silurian" down to Devonian, Carboniferous, Triassic, and younger periods. Many of these terrains have been discussed by Hinds.

In his summary account of the geology of the Klamath region Hinds (1933) divides later geologic time into three epochs—namely, pre-Nevadan, Nevadan, and post-Nevadan—in which the Nevadan epoch occupies the time of the post-Mariposa revolution of earlier writers. For the representative region in northern California discussed by Hinds (1935) he makes the following comprehensive statement, in accord with the views of Diller (1906), but including later notes of his own:

> "In the Klamath region the Middle Jurassic Potem and all earlier strata were very considerably deformed in post-Potem Jurassic and pre-Paskenta Lower Cretaceous time. Possibly this orogeny may have occurred prior to the Jurassic Knoxville epoch, but the presence of Knoxville strata overlying the sub-jacent Klamath complex has yet to be established"....

This epoch of the Knoxville series, and its relation to earlier and later times, already long considered by the writer, is one of unusual importance, concerning which there should be commensurate interest, since it constitutes a missing link in the chain of geologic events subsequent to the Nevadan orogeny, summarized by Hinds as follows: "C. post Nevadan, Upper Jurassic, Knoxville formation, in part probably present".

Although the areas referred to by Hinds lie generally north and east of the type areas of the Knoxville series the general region is the same, and its geologic history is inclusive of both, because they are contiguous in the Sacramento Valley. The "post-Potem Jurassic and pre-Paskenta time" includes that of Knoxville time, beyond all doubt.

THE GREAT VALLEY TROUGH

GENERAL STATEMENT

The inception and development of the Great Valley trough in post-Potem time was undoubtedly a major result of the Nevadan orogeny that closed Mariposa time on the West Coast, as in most Cordilleran regions. It would be interesting to review

the steps involved in its development, but the primary purpose of this paper is to trace the geologic history of the trough after its development. This history can be best traced in the deposits that accumulated within it.

Whatever terrestrial deposits may have been laid down in the trough in its earliest stages are deeply buried under marine deposits, and there is little to indicate their character or thickness. The earliest known deposits in the trough, from available information, are marine, as shown by their marine faunas, and these rest directly upon pre-Nevadan rocks of the Klamath complex, referred to by Hinds, that had been folded or otherwise deformed by the Nevadan orogeny. These pre-Nevadan terrains occupy most of the region embraced in Klamathonia, whereas the post-Nevadan deposits are now found largely within the trough or in its lateral extensions east or west. The character, description, and faunal aspects of these earliest post-Nevadan deposits have already been partly indicated by Becker (1885–1888), by the later accounts given by Diller and Stanton (1893–1908) under somewhat other terms, and by other writers, and need not be reviewed here.

ENVIRONMENT OF THE TROUGH

At its inception, as in later history, the Great Valley trough lay between the disconnected forelands of the continent in the Far West and the supposedly unbroken borders of the trough on the east. Concerning the eastern margin of the trough little is now known. From the viewpoint of known post-Nevadan sediment in the trough, the forelands during later Jurassic time played an important role, since they constituted the source areas for nearly all the terrigenous sediment that accumulated in the trough during this period and subsequent Mesozoic time.

From some unexplained, or unknown, cause little terrigenous sediment appears to have entered the trough from the east during post-Nevadan Mesozoic time, except its latest epoch. On the whole it appears that nearly 90 per cent or more of the known marine sediments in the trough lie upon its western border and exhibit the regional features and structural attitudes that should pertain to deposits coming into the trough from the west. No other source appears to have been possible. Detrital marine deposits, more than 40,000 feet thick are exposed on the western border of the trough, representing post-Nevadan time and denudation, which contrasts strongly with the aggregate of less than 5,000 feet of such sediment on its eastern border north of Mount Diablo.

RIVER DRAINAGE

It was shown by the writer (1938) that the sediments of the Shasta series in early Cretaceous time were a drainage product from the mountains of Klamathonia during this period and were gathered by an extensive river system that had carried them into the trough from the west during the early part of the period. Nothing was said as to the preceding epoch and its drainage system from these areas, although this might have been inferred from the discussion and the geologic map included in the paper. For the late Jurassic epoch similar environments and drainage conditions existed, and it was necessary only to trace those of early Cretaceous time back to late Jurassic to find conditions ancestral to Shasta time, and to infer that these had

been inherited from the preceding epoch. The late Jurassic sediments constituting the Knoxville series were also gathered by a river system ancestral to the Yolla Bolly River, which stream had followed the same course at an earlier epoch, had entered the trough at approximately the same gateway, had spread its sediments upon the floor of the same recently developed trough, and had there built up the earlier series of post-Nevadan sediments laid down within it. It was this series to which Becker (1885; 1888) should have restricted the name "Knoxville series", and the beginning of which he indicated as coinciding with the appearance of the genus *Aucella*, in post-Mariposa time. The subsequent record of the series he did not trace so well, since he assumed that it covered also the time of the early Cretaceous (Paskenta) group, now known to be distinct from the Knoxville. Accordingly he did not determine the full extent of his discovery, nor its subdivisions, which in truth may not yet be known completely, since an important part of its fauna remains to be discovered. Search is still in progress, and fragmentary remains of fossil mollusks indicate that its fauna is only partially known and far exceeds in classes, genera, and species the number known to Becker and White, or that is yet known.

It is not known whether the river systems of late Jurassic (Knoxville) time were as extensive as those suggested for early Cretaceous time, since the sediments of the former epoch are largely buried by those of Shasta time, which were spread extensively upon them. No earlier fossil-bearing Jurassic strata have been discovered in the areas of the trough as strictly defined, although they approach it in the areas discussed by Hinds, and also at Monte de Oro, as described by Diller. Land-laid deposits of some kind may occupy parts of the trough beneath the Knoxville sediments, but of this no evidence is known.

IMPORTANCE OF THE SERIES

The historical aspect and importance of the Knoxville series is best seen in its type area, from which its time factor can be more fully appraised. As here determined, the Knoxville series exhibits about 65 per cent of the thickness, and probably of the time duration, of the Shasta series that overlies it. From the viewpoint of geologic history its importance is seen especially in its position at the beginning of a distinctly new regime in West Coast physical and biological development. It is still too early in the study of its biological features and their faunal relations to determine fully its importance in this respect; this may be more satisfactorily attempted when they are more fully known. Fragmentary material seen in the field or collected indicates that its complete fauna greatly exceeds what has been assembled. As concerns the West Coast, probably the most important aspect of the series is that of a definite fingerboard for indicating the columnar position and relationships of other terrains with which the Knoxville is in contact below or above, or that may be correlated with it. What are its relations to the supposed next older unit in Coast Range geology—namely, the Franciscan series, or to any part of it? What are its relations to the economic mineral deposits known in the Coast Ranges and to other terrains, sedimentary or eruptive, with which it is in contact?

Fixing correctly the chronological position of this series should throw light upon other units in California and elsewhere on the West Coast. Its age determination

should contribute to the development of a reference scale for the Pacific Coast Mesozoic, including Alaska, Mexico, and other parts of the continent in which correlative deposits exist, and this aspect of its importance has wide application on other borders of the Pacific, in other latitudes and longitudes.

Deposits of Knoxville time were not confined to California. The seas of Knoxville time probably left contemporaneous deposits on many shores of the Pacific that will doubtless be recognized when sufficient search has been made. In part, at least, this search has already been made. Burckhardt (1906–1930) (and more recently Imlay) has discussed Mesozoic conditions and faunas in Mexico, including the later Jurassic (Portlandian and Tithonian), which clearly reflect the epoch and the stratigraphic column in California, embracing the Knoxville and older deposits, though he did not attempt their correlation. Burckhardt included (1930, Table 6, p. 64) a tentative suggestion as to the position of the "Knoxville beds" and (p. 80) compared the species "*Hoplites*" *storrsi* Stanton with "*Hoplites*" *calisto* (d'Orbigny) var., as Stanton had already done, and his views are supported by much pertinent collateral evidence. However, the diastrophic aspects of the Knoxville series have not been discussed by, or known to, any of these writers, and it may be that the tectonic history of the several regions did not wholly coincide.

PHYSICAL ASPECTS OF THE SERIES

HISTORICAL REVIEW

The distinctness of the Knoxville series from the Lower Cretaceous "Shasta group" of Whitney and Gabb (Whitney, 1869) was first recognized by Becker (1885; 1888) during the progress of his economic work in California, in part with the assistance of C. A. White. On account of the limited time at his disposal, the partial development of the series in the districts of his work, and the meager literature of the West Coast at the time, his views and his criteria left much to be desired.

Much work in these areas was later done by Diller and Stanton (1884–1894), and much progress was made as a result of their explorations on the west side of the Sacramento Valley, particularly farther north and in Oregon. They recognized the value of Becker's work and traced the Knoxville beds partially described by him as far north as the Cold fork of Cottonwood Creek, and farther but, like Becker, they did not differentiate this series from that of the Shasta series, as now understood. However, for this latest Jurassic sedimentary succession in the Great Valley trough, Becker had proposed the term Knoxville series. Later he (1888) gave it a definition, not wholly accurate, but serviceable, capable of emendment by later students of the subject, and more in accord with the physical facts and conditions pertaining to it and existing in the field covered by Becker, and later by Diller and Stanton. Although, in his discussions of the series, Becker's language often lapsed to other terms, the term Knoxville series, often employed by him, now appears to be the most fitting and appropriate term that has yet been applied to it. For its essential value and priority and for its relevant use in the literature, it should be retained, but clarified and emended upon the basis of its columnar position, disastrophic record, its fauna, and its limitations, rather than upon its faulty record in the literature, which record

has historical importance, although neither complete nor wholly correct, as will appear to those who read it.

Becker (1888, p. 180), after reviewing the several units in the Mesozoic column proposed by Whitney and Gabb (1869, Preface), opportunely proceeds as follows:

"To facilitate reference to the various groups of strata Dr. White and I have agreed to give local names to several of the California occurrences. The fossiliferous beds of the Mariposa estate will be known as the Mariposa beds; the group especially characterized by the presence of *Aucella* in the Coast Ranges will be referred to as the Knoxville series, because they are typically developed, and have been especially studied in the neighborhood of the mining town of that name".

This name is repeated thereafter in Becker's account and in those of later writers.

It is not claimed that Becker's use of the term is faultless or consistent, or that it fits well the geologic facts that he endeavored to portray, but, because of his first application of the name to these facts and of its essential value, the name now established in the literature should be retained and applied as the geologic facts appear to warrant. By the usage of Diller and Stanton (1894) the term was expanded to more nearly fit the facts. Diller (1908a, p. 392) states:

"The greatest mass of Knoxville strata known lies along the western side of the Sacramento Valley, in Tehama County, California, and although locally veined with calcite is not perceptibly metamorphosed".

In this area the stratigraphic thickness varies from 13,820 feet on McCarthy Creek to more than 16,000 feet on Redbank Creek, although here its original thickness is greatly reduced by faulting.

The term Knoxville series, rather than group, is appropriate for this succession, since it divides itself into three distinct groups of strata, as seen from their diastrophic records, their depositional relationships, their lithology, and their faunas. The higher group of the series, as thus limited, is overlain unconformably by the Paskenta group of the Shasta series, as already shown by the writer (1933–1938) and later recognized by others.

BASAL RELATIONS

The unmetamorphosed Knoxville series lies unconformably upon, and is readily separated from, the rocks of the Klamath complex. This unconformity is at once apparent in the lithological contrast between the almost unaltered Knoxville beds and the changeful, metamorphosed, and almost kaleidoscopic succession of the Klamath complex when traced along the strike of the contact zone. The older series varies greatly in different sections, from metamorphosed limestone and slates to siliceous or chloritic schists, to eruptive rocks of various types (greenstones, meta-diorite, meta-andesites), and cherts of various colors, including some that superficially resemble the Franciscan cherts as described and illustrated by Lawson (1895; 1914), and as generally recognized by many geologists.

The Knoxville series consists of a great succession of detrital sediment that is readily traceable to stream activity in the past, coming directly from the areas of the Klamath complex in the background to the west, and laid down in depositional order within the areas of the Great Valley trough. The Knoxville series cannot be

easily confused with the Franciscan group described by Lawson (1895) which lies considerably in the hinterland, occupying large areas of the Klamath Mountains west of the Great Valley of California.

THICKNESS OF THE SERIES

The thickness of the Knoxville series varies greatly in different sections in accord with local conditions of deposition and of subsequent history. On Redbank Creek, Tehama County, estimates based upon the Gregerson and Burger traverses aggregate as much as 16,300 feet. The thickness diminishes southward somewhat as follows: on Elder Creek, 14,500 feet; McCarthy Creek, 13,820 feet; south of Toms Creek, 14,000 feet, 13,000 feet, 12,000 feet; and at Bear Valley, 10,000 feet. At the south end of Bear Valley, the thickness hardly exceeds 6,000 feet, and at Wilbur Springs it is less than 3,500 feet. At the old Reed mine, and eastward, the thickness has been reckoned at 6,000 feet, or a little more; its lowest exposed beds are here infolded in serpentine, owing to a secondary disturbance affecting this unstable rock, well known in California and Oregon.

In the Berryessa Valley the thickness hardly exceeds 3,500 feet, and on Capell Creek and farther south it is further reduced or is interrupted by tectonic disturbances; in Pope Valley conditions are similar to those just described, and the series is only partial. Near Mount Diablo the series is incomplete, not exceeding 4,000 feet, and in the Diablo Range its lowest divisions have not been found. In no part of this range has either of the two lower divisions of the Knoxville series been discovered, and no part of the series is known to the writer north of Garzas Creek. On Quinto Creek, Panoche Creek, Los Vallecitos, Waltham Creek, and farther south where work has been done, only partial sections of the series are known, and the recognized upper beds of the series are much disturbed and in many areas are entirely absent. South of the Great Valley, as near San Luis Obispo, only partial sections of the Knoxville series are known, as represented by the "Toro formation", in which a general thickness of about 3,000 feet is known, containing the upper Knoxville species *Aucella piochii* Gabb, but only near its base, as described by Fairbanks (1904). As will be seen later these variations in thickness of the Knoxville series in different sections within the Great Valley and outside of it are due wholly to an overlapping of its higher portions upon basement terrains, owing to the progressive subsidence of coastal areas toward the south. The special history of the series has been locally differential, being most complete in its type areas in Tehama County, but progressively less complete toward the north and to the south, both within and outside the Great Valley. The portion of the series best known to Becker has the greatest longitudinal extension, whereas the areas of its greatest stratigraphic development were first known to Diller and his associates and are found in Tehama and Glenn counties, but neither to the north or to the south. Where the outlet (or inlet) of marine waters existed is not now known, though presumably both led toward the greater ocean—namely, toward the west. Without evidence to the contrary it may be assumed that this portal existed near the present outlet of the Russian River Valley, or immediately south of it.

GEOGRAPHICAL SPREAD

Becker's initial work (1885; 1888), with the co-operation of C. A. White, was soon followed by that of Diller and Stanton (1892–1908) who recognized the belt of the Knoxville farther north on the west border of the Sacramento Valley, and in part in western Oregon, the details of which are still unsettled. Up to recent years little has been definitely known as to the origin of the series, its position in the Mesozoic column, its stratigraphic volume, relations, limitations, or its subdivisions and their spread. The relations of the series and of its distinctive parts to the underlying terrains, and their distinctive faunal or other features, have hardly been regarded as deserving notice, either in California or on the West Coast.

In truth, much misunderstanding and confusion still exists as to its relations to other recognized terrains that border upon it in some areas. With regard to its faunas, a few of its species had been described by Stanton (1895), Pavlow (1907), Crickmay (1932), and others, many of which were mentioned by the writer in a preliminary paper (1933). Although further data concerning the series can now be given, a complete account of its stratigraphical and paleontological features cannot be claimed.

Every excursion into its areas has resulted in the discovery of further details not known before, and often of much importance to our knowledge of the whole.

The three important divisions of the series now recognizable do not have equal stratigraphic thickness or geographic spreads; the latest is much more extensive than the others, passing far south beyond the limits of the Great Valley and extending north far into Oregon. The older groups are restricted, as far as known, to the Sacramento Valley. Yet all these groups are embraced in the Knoxville series in the original sense of Becker, as can be shown.

In the Sacramento Valley the Knoxville series is well exposed in an almost continuous belt, 1 to 3 miles broad, extending longitudinally for nearly 100 miles, and in partial exposures for a much greater distance. (*See* Anderson, 1938, Pl. 84, for areal distribution.) It crops out at Mount Diablo, in the Diablo Range, and farther south near San Luis Obispo, on the upper branches of various rivers, as far south as the Santa Ynez River, or farther. It is not known south of the Santa Ynez Mountains, in California, or elsewhere. In the Diablo Range and southward, there is less regularity or continuity, since the series has suffered much from faulting and displacements, as have all later series and groups of strata on the flanks of Salinia, partly described by Reed (1936). Correlative strata are known in central and northern Mexico as shown by Burckhardt (1906–1930), and more recently by Imlay (1939).

In western Oregon Diller (1908a) has described in part the occurrence of the "Jurassic Flora of Oregon", as Knowlton had also done (1910), the northern limits of which have not yet been shown. Farther north correlative deposits are known, as will be shown, although their extent and other features cannot be stated.

TYPICAL KNOXVILLE AREAS

The Knoxville series as here described is typically developed in the eastern foothills of the front range of Klamathonia, on the western border of the Sacramento Valley,

in Colusa, Glenn, and Tehama counties, but only in small part in the areas adjacent to Knoxville itself. The district in which its strata were first distinguished by Becker (1885) and from which the name was derived lies near the southern end of the belt indicated for it by Diller and Stanton (1894) and here regarded as containing the most representative sections. Diller and Stanton traced the belt northward across its most typical areas to and beyond the Cold fork of Cottonwood Creek, though they did not clearly differentiate the Knoxville from the lower part (Paskenta group) of the Shasta series. However, from Stanton's later account (1895), it appears that he surmised that the beds here segregated as the Knoxville series represent a late Jurassic sequence, and this view coincides with that of other writers (Pavlow, J. P. Smith, Knowlton, and others). From the viewpoint of diastrophic history, the most complete and representative sections of the series are found in the areas first studied by Diller and Stanton, and designated by the writer (1933) as its type area. This area is included in the map of the region contained in an earlier publication by the writer (1938, Pl. 84), which in general covers the foothill belt between Wilbur Springs on the south and the north border of Tehama County. In this belt the Knoxville strata, standing at a high angle (60°–90°), dip normally eastward, their greatly denuded edges forming the floor beneath a connecting chain of valleys (Bear Valley, Indian Valley, Stony Creek Valley, Elk Creek Valley, and other areas north of Paskenta) that extends north to Redbank Creek and to the areas north of the Cold fork of Cottonwood Creek. In this belt of valleys the Knoxville strata crop out almost continuously, except where covered by alluvium. In most of the valleys named, fossils are abundant in some parts of the sequence, especially in those areas in which the ancient marine water had not been freshened by terrestrial streams.

North of Redbank Creek, Tehama County, the Knoxville strata become more sandy and conglomeratic and are partly overlapped by beds of the Shasta series, although in some places they rise to the surface; they terminate on the flanks of the front range northwest of the Cold fork of Cottonwood Creek in a manner to be described later. These beds are faulted against the rocks of the Klamath complex at some places, but the normal aspect of the zone is that of a depositional contact.

In the district about the Reed mine, at Knoxville, and at Wilbur Springs, depositional contacts are found, although in these areas the series is not complete at either top or bottom. In many places serpentine forms a part of the basement complex upon which the Knoxville beds were laid down, although this fact is often disguised by the unstable character of this terrain.

STRUCTURAL ATTITUDE

In its typical areas the usual attitude of the Knoxville beds is that of a simple homocline in which the strata slope from the basement rocks regularly toward the east, at varying degrees, often very steeply. In some areas the Knoxville beds are overturned locally, as illustrated in an earlier paper by the writer (1933, Pl. 62). Faulting is evident in some areas near the base, of a normal type resulting from uplift in the basement rocks and of settling in the loaded areas of the trough. There is little evidence of thrusting or excessive folding, except as stated above. In some places the faulting has resulted in considerable displacement, usually in the down-

drop of the strata, whereas in other areas little displacement has occurred relative to the basement rocks. Vertical displacement may nearly always be taken as evidence of uplift in the older areas to the west adjoining the line of contact, rather than downfaulting of Knoxville strata. There is little evidence of folding in these beds as a whole, except as here stated, and no duplication of strata by either faulting or folding. Only in the immediate neighborhood of the base of the series are the beds closely folded, and this seems to be probably due to tectonic disturbances in the basement areas, especially in those occupied by serpentines, but with some reactions in the adjoining Knoxville areas as well, although rarely has an important degree of metamorphism resulted.

There are two noteworthy exceptions to the concept of a homoclinal structure in the Knoxville series. One occurs about 4 miles north of the village of Stonyford, in southwest Glenn County, where a broad ox-bow curve in the Knoxville strata, as a whole standing at a high angle, surrounds a tongue of peridotite that protrudes into the valley from the west. The other occurrence is in the vicinity of Paskenta, where the Knoxville strata, standing at a high angle, show similar evidence of having been laid down about a tongue of older rocks. There is no evidence of metamorphic action upon the Knoxville series. Between Clear Lake and Knoxville many areas exhibit evidence of the pre-Knoxville age of the peridotites, which throughout the Coast Ranges are more closely associated with the older, pre-Knoxville rocks, as soon becomes evident to a geologist traversing the region of the Klamath Mountains, where no Knoxville beds are known.

VOLUME OF SEDIMENT

Within the limits of its type areas the volume of Knoxville sediment may be tentatively computed, but without an assurance that these estimates are wholly trustworthy. If we take 11,500 feet as their average thickness, which is a fair estimate, an average width of their belt beneath the floor of the valley as 25 miles, and a longitudinal extension of 96 miles, the resulting figure representing their volume would be 5,200 cubic miles, and a maximum estimate might exceed 6,500 cubic miles.

In these estimates no account is taken of the quantity of material carried away in suspension or solution by the currents passing out to sea. The calculated volume of sediment remaining in the basin of deposit cannot, therefore, be taken as the entire product of denudation on the land areas of its origin, and for such purposes the estimates are deficient.

AREAS OF ORIGIN

The areas of origin of the Knoxville sediments were commensurate with their volume and were accordingly large. If we may be guided by the larger physical features of the region during Shasta time, rather than those of the present, these areas were occupied by mountainous land, the principal drainage from which was discharged into the Great Valley trough by a river system entering it at, or near, the locus of discharge point of the "Yolla Bolly River" described by the writer (1938, p. 29–30). The geologic map there given for this region, and for later Mesozoic terrains, approximates the writer's views as to many of its aspects during both

Knoxville and Shasta times. The drainage assembled in the Yolla Bolly basin during Knoxville time flowed eastward and transported much of the Knoxville sediment now found in the northern sector of its belt. Calculations were offered by the writer (1938) as to the areas of origin for the Shasta series, but, as the source areas of Knoxville sediment were far in the background of Shasta time, these calculations may possibly not apply well to the problems of the earlier series, though they probably indicate the magnitude of its areas of origin. Little is definitely known concerning the changes that occurred in the interval of time, which was not long, between the Knoxville and Shasta epochs. In large part at least, the areas of origin for both series were the same. Moreover, we may assume that the drainage conditions described for the Shasta epoch (1938) were to a great extent inherited from those of the Knoxville epoch and to this extent were reflected in them. Little more can be said now.

Some hint as to the sources of the Knoxville series and to the episodes of its epoch may be gained from a stratigraphic analysis of the series itself.

LITHOLOGICAL CHARACTER

As the Knoxville sediments are almost wholly detrital in origin, they consist of conglomerates, sandstones, and shales, although as found in the type areas their relative importance is not in the order named. In volume shales predominate, and conglomerates may be placed last. These facts no doubt reflect the results of diastrophic activity during the epoch of sedimentation and for this reason merit especial attention and study. Shales dominate the lower third of the series wherever it is exposed and in some areas, as on Beegum Creek, include carbonaceous beds, though without known plant remains.

These lower shales are in some places greatly indurated as a result of the pressure due to the great thickness of the series and that of the Shasta series superimposed upon it, now largely removed by denudation during long Tertiary and Cenozoic times. Such indurated shales, locally reddish and cherty, are exposed in various areas, though not in all sections, and are found at the base of the series and at places at higher levels. At the base of the section, such indurated shales are exposed a mile or more north of Redbank Creek, on some branches of Elder Creek, to the north of Toms Creek, south of the Covelo road on the west branch of Bennett Creek, and on some branches of Stony Creek, although in some areas they are overlapped by later beds of the series and are not seen.

In the Toms Creek area, on the west branch of Bennett Creek, these shales rest directly upon serpentine or upon other basic igneous rocks that form a part of the Klamath complex, here constituting the floor upon which the Knoxville sediments were laid down. Higher in the series occurs the principal body of conglomerates, as shown in the McCarthy Creek section illustrated in an earlier paper by the writer (1933, p. 1245). These conglomerates are exposed in the prominent ridges east of Bennett Creek, south of Toms Creek, and south of the Paskenta-Covelo road. As one ascends the mountain west of Bennett Creek on this road, the reddish shales are conspicuous to the south, standing at a high angle and dipping eastward, but in the

canyon of the West branch of Bennett Creek they rest directly upon basic dioritic rocks that form a part of the Klamath complex.

These lower shales of the Knoxville series have sometimes been mistaken for facies of the Franciscan series, the cherts of which they resemble superficially. But this latter series is much older and in this region lies generally farther west, where it occupies a broad belt in the Klamath Mountains. These lower shales of the Knoxville series carry many fossils, including *Aucella*, belemnites, and ammonites to be described later. There is little resemblance between the Knoxville series and the Franciscan, as correctly understood, in their geographic spread in the Coast Ranges, their lithologic composition, or in their mineral or faunal contents.

LITHOLOGICAL ALTERATION

In many areas at or near the base of the Knoxville series some degree of alteration in its lower sandy shales has been noted. This alteration has been mentioned by Fairbanks, Turner, Lingren, Lawson, and others, but its interpretation and the evaluation of its importance vary widely, perhaps in accord with the predilections of the observers. However, the sandy laminated shales at the base of the series appear to have suffered much from compression, crushing, distortion, and crumpling due to excessive pressure from superimposed strata and to some thrusting. The degree of alteration in these beds varies greatly as traced along their contact zone from one district to another and appears to have been greatly influenced by the underlying basement rocks. In successive areas between Redbank Creek, Tehama County, and Wilbur Springs, Colusa County, the rocks of the Klamath complex vary from ancient, thin-bedded siliceous schists, limestones, cherts, and metamorphic rocks of Paleozoic ages to old eruptives, metadiorites, peridotites, serpentine, meta-andesites, dike rocks, and other uncertain types.

Where Knoxville strata lie in contact with the older and more stable rocks (siliceous schists, cherty beds, meta-andesites, or limestones), as on the Alder Springs road, west of Chrome, or on Toms Creek, they are but little altered. In areas in which these shales are in contact with serpentine, or other unstable rocks, as near Redbank Creek, Stonyford, or Wilbur Springs, and at other points, the character and the degree of crumpling and alteration may be somewhat increased, and the aspect of the contact beds changes accordingly. In extreme cases, which are always local, this has led some observers to regard the rocks as being "metamorphosed", but, if this term can be properly employed (except quite locally), it is the lowest type of metamorphism, such as hydrothermal change, which has produced no new minerals nor recrystallization of the original material. Only locally, where secondary (later) disturbances in serpentine has taken part in the process, is such alteration found. In most places seen by the writer, the alteration of the beds is such as might result from hydrothermal action or from the infiltration of water at high temperature, charged with calcium or magnesium carbonates, or other materials soluble under such conditions. In extreme cases in which the shales have been most disturbed, distorted, crushed, fissured, and physically altered, thin veins or bunches of quartz are sometimes found. Such alteration has often changed the outer aspect of the rocks in some degree, although limited to a few hundred feet, and in no place approaches

metamorphism, such as is known in the Mariposa beds in the Sierra Nevada. In truth it is not metamorphism in a technical sense, nor does it greatly resemble such condition.

MINERALIZATION

No important occurrence of economic minerals, except secondary occurrences of cinnabar due to distillation by moderate heat and pressure are known in the Knoxville beds, although they often occur in the basement rocks near the contact, and in rare cases they have reached secondary lodgement in the shales. Most of the economic minerals, other than petroleum, are most abundant in the basement rocks, although in some places very near the line of contact with the Knoxville beds. Some mercury ore bodies have been reached by tunnels driven through Knoxville beds, as at Knoxville, the Reed mine, New Idria, and at other places. Nearly all the prospecting for cinnabar has been in pre-Knoxville rocks, and only exceptionally has cinnabar been found in Knoxville or younger formations. In this respect the shales and other rock types of the Knoxville series contrast greatly with those of the adjacent pre-Knoxville rocks, which have supplied 95 per cent or more of the Coast Range economic minerals. In point of quantity produced, the Knoxville series is wholly negligible.

DELTAIC ASPECTS OF THE DEPOSITS

The Knoxville sediments, like those of the Shasta series, are deltaic in composition and character and in their relations to the river systems to which they owe their origin. The same aspect is seen in the distribution of the materials brought into the basin of deposition, especially in the two later groups. This feature is less obvious in the Elder Creek group than in the later groups, since it is largely covered by them. However, the materials composing the Knoxville were brought into the basin by almost the same drainage system that later carried the Shasta sediments and were spread in like manner upon its floor as the first contribution of marine sediment.

The deltaic character of these deposits is probably best exposed and best seen in those of the Grindstone group, as here described. These sediments, however, are not all the product of a single river issuing from the background, but of two or more streams, each having its individual character, sedimentary features, and history. The most northerly of these streams now accessible had largely developed the course later occupied by the Yolla Bolly River (Anderson, 1938), and its delta is now largely overlain by that of the Shasta series, having essentially the same areal spread. The older delta is partly represented by the conglomerates of the Grindstone group exposed south of Beegum Peak on the slopes of Tedoc Peak, near the point of river discharge, and by the finer sediments found from this point southward. A similar but better illustration of the same character is seen immediately south of Toms Creek and on the Covelo road, just east of Bennett Creek, in the parallel ridges extending south along the line of strike. These beds represent the lower part of the Grindstone group, as already shown. Other deltaic areas are to be seen on the South fork of Cottonwood Creek, on Elder Creek, and on other streams that issued from the background of the Knoxville series. However, these delta areas have all suffered denudation

and waste and on their eastern borders are in part overlain by later sediments of the Shasta series, from which they are distinguishable by their faunas or stratigraphic relations.

Near the delta head in the areas south of Beegum Creek, the sediments are coarser than farther south, due in part to the dropping of the heavier elements of the river-borne drift from the slackened currents. In the delta area adjacent to the South fork of Cottonwood Creek, conglomerates dominate the section, although according to Diller its lower beds (? Elder Creek group) are composed of sandy shales. Plant remains are abundant in some places, and fossil wood has been collected, including fragments of wood, probably of *Sequoia*. In the Newville group many pieces of fossil wood have been found, with fragments of leaves more or less carbonized, and veinlets of lignitic material are common in the Newville group on McCarthy Creek. None of these have been found in the Elder Creek group of the series.

COMPOSITION OF THE KNOXVILLE SERIES

GENERAL CONSIDERATIONS

The Knoxville series is not a simple, undivided sequence of strata, as it is often assumed to be, but it exhibits a varied diastrophic record. As exposed on the more important streams that cross its belt in its typical areas, it readily divides itself into three quite distinct groups of strata, in the following order:

	Maximum thickness (Feet)
3. Newville group, latest	4,000
2. Grindstone group, middle	5,400
1. Elder Creek group, earliest	6,600
Aggregate	16,000

These groups continue distinct throughout the belt of the series in its typical areas on the west border of the Sacramento Valley. They are not equally exposed south from Beegum Creek, or from Redbank Creek, but show individuality in their distribution, not only throughout the Great Valley but outside of it.

The long time interval that elapsed during the deposition of this succession spanned many diastrophic episodes on the West Coast and within the Great Valley and at least three intervals of readjustment. These adjustments may well have been due, in part, to the loading of the basin floor, quite independent of the diastrophic susceptibility of the West Coast. The precise causes of the diastrophism may never be known, but the fact of their operation and results during Knoxville time cannot well be disputed or set aside, even though they have long been overlooked. Their operation during Knoxville time is not difficult to trace, as it extended throughout the Great Valley and farther.

These several groups of the series are well characterized lithologically and faunally, and, as shown herein, their distinctness is reflected in the topography as well. The central group, consisting largely of coarse detrital materials in most places in its belt, is thereby protected to a considerable extent from degradation, and accordingly it stands in relief above the lower and the upper groups between Toms Creek and Bear

Valley, a distance of more than 45 miles. These features are recognizable also north of Toms Creek and on Elder Creek, Redbank Creek, and farther north. However, as will be seen, the more important evidence of distinctness in these groups is in their geographic occurrence and in their faunal features, each group possessing individual differences in lithologic character and in faunas not seen by the casual observer.

ELDER CREEK GROUP

This earliest group of the Knoxville series is traceable northwest from Redbank Creek for only a short distance and is then overlapped by early Shasta (Paskenta) beds. Toward the south it is readily traced, though not continuously, for more than 40 miles to the latitude of Elk Creek village. A mile or more north of Redbank Creek its lowest exposed beds may be seen in a canyon leading northward between a bold serpentine ridge on the west and the foothills on the east. Only part of the basal beds are exposed here, but the lowest seen consist of dark reddish-brown, greatly indurated shale or thin-bedded cherty strata standing at a high angle and in part slightly overturned. A little higher in the section the strata become more normal and dip away from the serpentine, which here forms a part of the Klamath complex. On the South fork of Cottonwood Creek similar conditions are found, as also on the main fork and branches of Elder Creek, where the lowest exposed beds show the same general relations, although the dark cherty beds of the group are not exposed. On the branches of the south fork of Elder Creek, near the Pellow's place, the lowest exposed beds of the group rest upon or against pre-Knoxville meta-andesite of the Klamath complex, which is traceable southward toward Toms Creek. On the mountain road north of Toms Creek, leading west from Paskenta, the basal beds of the Elder Creek group are exposed and toward the north are readily traced for 6 or more miles. Here also the basal beds rest directly upon meta-andesite in depositional contact, traceable for many miles to the north and to the south. The contact zone at the base of the Knoxville, free from complications, shows clearly the relationship of the Knoxville beds to the Klamath complex as one of deposition. The basal beds of the Knoxville are here greatly contorted for a thickness of 50 to 60 feet or more, and greatly altered, compressed, crumpled, and otherwise physically changed, but they are not metamorphosed, showing no evidence of recrystallization in the true sense, but rather a considerable degree of alteration, of a purely physical character, with the production of no new minerals.

A few miles farther south, on Toms Creek, a mile or more above the mouth of Bennett Creek, quite similar conditions are found. The contact zone is well exposed, showing a small fault, with little displacement. The basement rock is a quartz-chlorite schist, overlain by the Knoxville beds, here also apparently in depositional contact. The basal beds of the Knoxville are here greatly altered, contorted, and crumpled as if from thrust and carry traces of serpentine, which on the Covelo road forms a part of the Klamath complex. The alteration of the Knoxville beds here may be regarded as a hydrothermal change only, in that they show no metamorphism of the character known in the Mariposa beds, although they carry much calcium or magnesium carbonate, seemingly introduced by infiltration by water.

This group of the Knoxville series is well exposed at most places between Redbank

and Toms creeks and in the triangular area immediately south, everywhere maintaining a general thickness of 6,500 to 6,600 feet or more; 4 miles south of the Covelo road it is overlapped by the conglomerates of the Grindstone group, which farther south in many areas rests directly upon rocks of the Klamath complex. The Elder Creek group is not known to outcrop between Elk Creek village and Cooks Springs, west of Lodoga, except locally in the ox-bow area north of Stonyford. In most places between the Covelo road and Cooks Springs only a narrow belt of the older group is traceable at intervals, though this narrow belt expands somewhat near the west border of Bear Valley. It can be shown that for more than half the distance in which the basal contact of the Knoxville is traceable south from Redbank Creek, the Elder Creek group is but little exposed, being for the most part overlapped by the Grindstone group, but as seen on Toms Creek and northward the Elder Creek group is well exposed.

The Elder Creek group in no way resembles any part of the pre-Nevadan succession described by Diller or Hinds (1935) in the Klamath-Pitt River region, but rather it constitutes a part of the post-Nevadan Knoxville series, as shown by its fauna and lithological character, and includes only such rock types as are common in other parts of this succession. Its faunas are dominated by *Aucella*, although they contain belemnites and ammonites. The lower beds of the group as found on the South fork of Elder Creek, contain species of *Aucella*, at 1,200 feet above the base, and a little higher in the section R. L. Rist and the writer collected *Aucella sollasi* Pavlow and *Aucella gabbi* Pavlow.

At a horizon 1,000 feet higher in the section Rist collected the holotypes of *Kossmatia tehamaensis*, nov., and *Pecten* (*Chlamys*) *risti*, nov., and species of *Aucella*. In the Bennett Creek area, north of the Covelo road, a thick succession of alternating thin-bedded shales and calcareous sandstone layers constitutes a major part of the Elder Creek group, as is the case north of Toms Creek in the area traversed by the mountain road leading west from Paskenta. In these areas the Elder Creek group rests directly upon the chloritic quartz schist or the meta-andesite indiscriminately, both of which belong to or form a part of the Klamath complex, as recognized by Hinds.

On the south bank of Toms Creek, about 2,000 feet above the base of the Elder Creek group, Cross and the writer found a small species of *Aucella*, greatly resembling *Aucella bononiensis* Pavlow, and the holotype of *Belemnopsis californica*, nov., and at about the same horizon a mile or more below Bennett Creek, J. B. Johnson, of Corning, found the holotype of *Belemnopsis tomsensis*, nov., and species of *Aucella*.

No part of the Elder Creek group can be identified with any portion of the Franciscan series of Lawson, which it little resembles and which appears to form a part of the Klamath complex farther west.

GRINDSTONE GROUP

General considerations.—The central group of the Knoxville series begins at the north with a well-marked basal conglomerate exposed in sec. 26, T. 28 N., R. 9 W., where it rests directly upon the Klamath complex on the northeast slope of Tedoc

Peak, northwest Tehama County. About 8 miles to the southeast, west of Stephenson's Peak, these conglomerates overlie the Paleozoic limestones mentioned by Fairbanks (1894, p. 88). A few miles south of Cold fork, a part of the Elder Creek group is exposed, and from this point south for many miles the conglomerates lie discordantly upon a floor of the Elder Creek group in the manner of a disconformable overlap and constitute a definite belt that stands in relief along the strike of the beds. This ridge is seen just west of Blue Canyon, where its beds overlie the Elder Creek group. South of Blue Canyon the belt of this group crosses the South fork of Elder Creek west of Cooper's place, mentioned by Stanton (1895, p. 15). From this point south, the belt is marked by a prominent ridge extending south to Toms Creek, 1.5 to 2 miles west of Paskenta, where the belt of the Tedoc conglomerate describes an ox-bow curve that crosses Toms Creek and curves to the west along its south side in a prominent ridge extending toward Bennett Creek. Near the Covelo road, east of Bennett Creek, the belt of this group turns to the southeast, marked by two prominent parallel ridges of conglomerate and dark sandstone, traceable south from Toms Creek, to which they probably owe their origin. Immediately west and northwest of these ridges the Elder Creek group is well exposed, having a thickness of 6,600 feet or more. The basal beds of the Grindstone group here rest discordantly upon the earlier group, as shown by the strike. Toward the south the parallel ridges of the group are easily traced, except at short intervals, southeast to the Bartlett Springs road leading west from Leesville, a distance of more than 45 miles. The identity of these beds with those at Bennett Creek is beyond question.

The Grindstone group takes its name from the stream of this name, which crosses its belt 1 to 2 miles west of the road between Chrome and Elk Creek village. At this locality it has a thickness of 5,400 feet. On Redbank Creek the thickness is much reduced by faulting to about 2,800 feet, as shown in the Gregerson and Burger section.

On Grindstone Creek the belt is readily recognized by its conglomerates and sandstones, the latter containing many zones of *Aucella* in which other molluscan types are rare. West of Chrome a residual early Pleistocene terrace deposit conceals the lower beds of the group, but immediately south they rise against the Klamath complex, and at the Hull ranch the conglomerates have a thickness of 2,200 feet, overlapping the Elder Creek group and resting against the older complex. This condition continues south to the Alder Springs road and much farther.

In September 1936 Taff, Cross, and the writer carefully studied the contact conditions of the Knoxville beds upon the Klamath complex at many points west and south of Paskenta, some of which have already been mentioned. On the Cooks Springs road, 3.5 miles southwest of Lodoga, they found a "near contact" zone between a coarse black sandy shale of the Grindstone group and the serpentine upon which it appears to rest. The details of the contact are at places obscure, and there may have been some faulting, with a downdrop of the strata against the older rocks, though this was not proved. This locality had been previously examined by H. O. Jenkins and the writer, with the same conclusion.

On the Alder Springs road, about 3 miles west of Winslow, the pebbly beds of the

lower Grindstone group, standing at a high angle, were found to lie against the siliceous chloritic schist of the Klamath complex; this point had also been previously studied by Jenkins and the writer. Here is a clearly normal contact, with no crumpling of the Knoxville beds and no trace of alteration in them. Only a slight or negligible occurrence of serpentine was found associated with the older rocks, possibly due to a secondary "squeeze" of this material into the contact zone. The lack of alteration in the Knoxville strata was striking.

At the Hull ranch, a little north of Grindstone Creek, on the new Forestry road was found about 2,200 feet of pebbly beds of the Grindstone group resting directly upon (or against) serpentine. Overlying these pebbly beds is a great thickness of Knoxville sandstones and shales. The beds in contact with the serpentine show no evidence of alteration and only a small degree of distortion. Similar conditions were found in the Grindstone group farther north, near Bennett Creek.

In 1934 H. O. Jenkins and the writer traced the contact zone north from the Bartlett Springs road to the vicinity of Cooks Springs, a distance of 8.5 miles. In this part of the zone the contact is between the upper beds of the Elder Creek group and serpentine at many points. The contact is apparently one of some faulting, and the beds are in some places much broken, distorted, and veined with calcium or magnesium carbonate. There is no evidence of metamorphism or great alteration in the Knoxville strata along the entire distance. The alteration in these beds on the contact zone is much less than that seen on Toms Creek between the lower beds of the Elder Creek group and the chloritic schist of the Klamath complex. No Franciscan rocks were found in contact with the Knoxville beds in this part of the belt, although their presence was noted farther west, on the Bartlett Springs road.

The Reed mine.—At the old Reed quicksilver mine, 4 miles northwest of Knoxville, strata of the Knoxville series are exposed between ore-bearing pre-Knoxville rocks on the southwest and serpentine on the northeast. No beds of the Elder Creek group occur here, and on both lithologic and faunal bases these Knoxville beds are assignable to the Grindstone group. The beds have a maximum thickness of about 1,650 feet and appear to represent the basal part of the group, of which the lower two-thirds consists of conglomerates, sandstones, and sandy shale, and the upper part of pebbly conglomerates, above which are sandstones. The pebbles of the conglomerates are of varied rock types, including variously colored cherts, such as are well known in the Paleozoic areas of the Klamath complex, slates, limestones, and quartzites, and a smaller number of porphyrites, metadiorites, and other igneous types, ranging from pea size to fist size or larger. Many of the chert pebbles show fractures and a degree of mineralization, with secondary silica, pyrite, and small pits containing iron oxides. Indurated portions of the sandstone contain pyrite and other secondary minerals.

On the old grade half a mile above the Reed tunnel, on the west side of Davis Creek, in the shaly sandstone were found numerous examples of *Aucella sollasi* Pavlow, *Aucella* cf. *A. pallasi* Keyserling, and other species of the genus, but other types were lacking.

Half a mile upstream, on the west side of Davis Creek, mercury ore taken from a recent tunnel contained unmistakable evidence of petroleum, recalling the fact men-

tioned by Becker (1888). No part of the Knoxville beds here described shows either metamorphic action or any marked degree of alteration, notwithstanding their proximity to serpentine and their infolding within masses of this rock. The Knoxville beds are practically unchanged by the presence of serpentine, especially in the contact zone east of the Creek. These beds, although enclosed between masses of serpentine, show no evidence of metamorphism and only a slight degree of alteration.

Briefly, no evidence was found that the Knoxville strata in this area had been intruded by serpentine, but on the contrary the more significant facts seen here by the writer support the view that a secondary or later disturbance primarily connected with the serpentine had resulted in the infolding of Knoxville beds between masses of this rock, or between segments of the floor upon which these beds had been laid down. This floor had formed a portion of the Klamath complex, which, owing to its instability, had yielded to the tangential stress affecting this region in post-Knoxville time. This view is in harmony with the results shown by many other disturbances to which serpentine is susceptible in the Coast Ranges of California, particularly since late Jurassic time, covering many epochs of diastrophic activity.

Wilbur Springs area.—The precise stratigraphic position of the Knoxville strata exposed near Wilbur Springs, Colusa County, is not wholly clear, since there are conflicting evidences as to their age not found in other areas but possibly due to an overlapping by strata of the Grindstone group upon beds referable to the Elder Creek group. Certain steeply inclined beds outcropping on the west side of Bear Creek, chiefly south of Sulphur Creek, carry a fauna referable to the Elder Creek group—namely, with *Kossmatia* aff. *K. tenuistriatus* Uhlig, *Aucella bononiensis* Pavlow, *Aucella mosquensis* (von Buch), and other species.[1] On the contrary, species of *Belemnites* collected by Taliaferro and students, and certain other aspects of the area seem to conform more nearly with these of the Grindstone group occurring in other areas not far distant. None of the finely striated species of *Aucella* that might indicate older strata of the Elder Creek group have been seen here, and the presence of petroleum on Bear Creek seems to indicate beds of a later group—namely, those of the Grindstone group, as at the Reed mine, farther south. It is, of course, possible that beds of the Grindstone group overlap, leaving exposed only a narrow belt of the Elder Creek group, but proof of this is lacking. No species of *Belemnites* have been found by the writer in this area, although they may occur here.

NEWVILLE GROUP

The upper division of the Knoxville series, well exposed near Newville, northern Glenn County, constitutes a distinct group in its succession, as seen in its lithologic features, its areal spread, and especially in its faunal aspects. In its type area its strata are predominantly dark argillaceous shales that contrast greatly with the sandstones and conglomerates of the Grindstone group as found in its type district. At the top the group contrasts greatly with the overlying conglomerates of the Shasta

[1] Spath (1923, p. 306) has mentioned *Kossmatia*, *Durangites*, and *Steueroceras* as occurring in "Knoxville" strata in California. These names were listed with *"Olcostephanus mutabilis"* Stanton, which has since been shown to be a true *Dichotomites* Spath, belonging well up in the Paskenta group (Valanginian) of the Shasta series, and has nothing to do with the Jurassic *Ammonites mutabilis* d'Orbigny.

series, as shown by the writer (1933). Its distinctness from the preceding groups is shown by its longitudinal and lateral expansions beyond the limits of the older groups, whereby its deposits rest unconformably upon pre-Knoxville terrains in distinct overlaps, which in many areas are emphasized by basal conglomerates. This condition of overlap of the Newville group upon older rocks is well illustrated at Mount Diablo, as mentioned by the writer (1938, p. 40), and in the Diablo range, as seen by Bennison and the writer in Merced County, near Quinto Creek, at Hawk Rock, where Bennison collected Jurassic fossils, including *Oppelia* (*Streblites*) *quintoensis*, nov., *Haploceras pachecoense*, nov., *Aucella krotovi* Pavlow, *Aucella andersoni* Pavlow, and other types of invertebrates.

Similar beds appear to outcrop in the Waltham Creek Valley, southwest of Coalinga, Fresno County. In the stratigraphic section given by Pack and English (1914), there is at the base of the section about 3,500 feet of shaly beds underlying a bed of conglomerate, which bed carries *Neocomites neocomiensis* (D'Orbigny). There is other indirect evidence that these lower shales represent a Knoxville (Newville) horizon, although final proof of this is lacking.

Outside the Great Valley, in the vicinity of San Luis Obispo, and farther northeast, Fairbanks (1904, p. 3) described and mapped the Toro formation. Fairbanks referred this formation to the Knoxville "group", giving its thickness as 3,000 feet. In 1894 Fairbanks and the writer collected, from the shales of this formation on the Eagle Ranch, *Aucella piochii* Gabb, and later the writer collected, from the same shales 3 miles northeast of San Luis Obispo, *Aucella piochii* Gabb and *Aucella hyatti* Pavlow. More recently Taliaferro obtained examples of *Hibolites toroensis*, nov., and other types of Jurassic aspect from the lower shales of the Toro formation on Old Creek, on the north border of sec. 30, T. 28 S., R. 11 E., M. D. M. All the species from the Toro formation seen by the writer are referable to the Newville group of the Knoxville series, although Fairbanks had regarded the Toro formation as of Cretaceous age, in accord with the practice then current.

The belt of the Toro formation, as shown on the State geologic map (1916), is traceable from the district of San Luis Obispo southeasterly to the Nipomo quadrangle and to the area described and mapped by Taliaferro (1943, p. 109) as Knoxville, from which he obtained the fauna determined by Crickmay (1932) as Tithonian. It is traceable into the drainage area of the Sisquoc River in central Santa Barbara County. The same sequence of strata, and under similar conditions of occurrence, has been described by Richard Nelson on the upper branches of the Santa Ynez River farther south. In Nelson's account (1925, p. 339–343), wherein he describes the geologic aspects of the areas about Little Pine Mountain, we may well substitute the term Newville group for his "lower Knoxville." In the language of Nelson (p. 341) we read: "Beds of fine quartzite and chert conglomerate occur near the base of the (Knoxville) formation in the eastern part of the district, but none have been observed elsewhere". The account given by Nelson illustrates the abrupt and widely extended longitudinal expansion of the Newville group toward the south, beyond the areas of the older groups of the series, which are confined to the Sacramento Valley. The thickness of the group in this area is given by Nelson as "more than 5,000 feet", and its fauna consists of "large numbers of specimens of *Aucella*

piochii", though he mentions no other species. This species occurs abundantly at Newville and especially characterizes the group.

Similar northward expansions of the Newville group are found in southern Oregon. On Wolf Creek, north of Grants Pass, *Aucella piochii* Gabb occurs in great numbers in some beds, as seen by the writer, although not before recorded.

Farther north, near Riddle—namely, at Buck Peak, as described by Diller (1908)—similar evidence of the Newville group is found, though no older Knoxville beds have been described or found here, or in this area. The "Jurassic Flora of Oregon" occurs about 1,200 feet beneath the horizon of *Aucella piochii* Gabb at this place.

In California, in the environs of the Great Valley, lateral expansions of this group beyond the limits of the older groups are shown on the general map, west of Knoxville, in Morgan Valley, and in the vicinity of Reiff, southern Lake County, as described later.

In the Sacramento Valley, in the typical areas of the series, in Glenn and Tehama counties, the Newville group is readily recognized by its distinctive faunas, wherein it differs greatly from the older groups of the series, and it differs also lithologically.

In the section on McCarthy Creek (Anderson, 1933), shales predominate, but with intervals of sandstone. At the Oake's place, near Cooper's, the beds become more sandy but they are the shales from which Stanton (1895) listed "*Hoplites*" *storrsi*, *Belemnites tehamaensis*, *Phylloceras knoxvillense*, and *Aucella piochii* Gabb, characteristic of the group.

This group includes the locality described by Stanton (1895, p. 16, 17) as 3 miles northwest of Paskenta, containing *Rhynchonella schucherti* Stanton, *Aucella piochii* Gabb, and many other types of Mollusca. The locality was at first thought by the writer (1933) to be referable to the Shasta series, from its number of pelecypod species, but the later discovery of its outcrop has placed it in the Newville group. Thus it was correctly determined by Stanton as Knoxville. The maximum thickness of the group near Chrome is estimated at about 4,000 feet; farther south it diminishes, owing chiefly to an overlap on its eastern border by beds of the Shasta series. The Newville group consists largely of dark crumbling shales, which in some areas contain concretionary beds, the concretions often holding well-preserved molluscan fossils, including many cephalopods. This group is well exposed northwest of Paskenta, on McCarthy Creek, west of Henderson's, on the South fork of Elder Creek, south of Newville, and at the old village of Winslow, and southward to Elk Creek village, beyond which outcrops are not known. An excellent exposure of the group is found on Watson Creek, 6 miles north of the Winslow bridge (Loc. 28,037, Calif. Acad. Sci., described later), where a representative fauna has been collected by the writer and others, including numerous examples of ammonites, belemnites, and pelecypods, the later chiefly species of *Aucella*

Strata of this group occur in many widely scattered areas, both within and outside the Great Valley. Only a few of the leading localities will be described as examples to show its distribution.

At Knoxville only the lower half of the group is exposed; its higher beds are overlapped on the east by the lower beds of the Shasta series, with *Aucella crassicollis* Keyserling, *Aucella inflata* Toula, and *Aucella terebratuloides* Lahusen. The dark

shales of the Newville group are exposed near the site of the old furnace, now largely removed. Only a few species or examples of *Aucella* were found near the old furnace site, including *Aucella piochii* Gabb, *Aucella russiensis* Pavlow, *Aucella knoxvillensis*, nov., and fragments of other species. One mile north of this point, and in the strike of these beds, the last-named species occurs in concretionary blocks. Neither belemnites nor ammonites have been recorded from Knoxville, although both have been collected from similar strata 3 miles north, on the east border of Davis Creek Valley, by Taliaferro and his students. Although this locality was selected by Becker (1888) as representing the series, unfortunately it exposes only a portion of the uppermost group of the entire series of the Knoxville.

OVERLAP AREAS

General statement.—In many areas in which Knoxville beds are known, the strata represent only the uppermost portion, the Newville group, as shown in the following pages. West of the serpentine areas that occupy an irregular belt extending north and south to the west of Knoxville, Reiff, and Wilbur Springs, are detached areas of Knoxville strata noted by the writer (1938, p. 51) and partly shown on the general map of the region, as an illustration of an important fact. In the area of Cache Creek, on the Williams-Clear Lake road, Taff, Cross, and the writer (1936) collected species representing a Knoxville horizon, including *Aucella piochii* Gabb and a perisphinctid ammonite, showing the presence of the Newville group in this area. Its beds rest in part directly upon an area of serpentine exposed west of the Napa-Yolo County line. This area of Newville beds constitutes an overlap upon older pre-Knoxville rocks.

Northwest of Knoxville, in the vicinity of Reiff, areas of Knoxville beds containing *Aucella piochii* Gabb are overlain by Shasta beds, as indicated on the general map by the writer (1938); these overlapping beds are clearly part of the Newville group.

On the west border of the Berryessa Valley, Napa County, steeply inclined Newville strata overlaid on the east by lower Shasta beds outcrop in a longitudinal belt for a distance of 12 miles or more; both groups are well supplied with fossils. The Newville beds of this belt have a maximum thickness of 3,500 feet and are traceable north to Knoxville, where the strata are overlain by lower Shasta beds, as already shown.

At the south end of Berryessa Valley, on Capell Creek, similar beds contain species of *Aucella* and *Belemnites* (*Cylindroteuthis*) sp., showing their position to be that of the Newville group. Similar beds crop out on the south side of Pope Valley and contain *Belemnites* (*Cylindroteuthis*) sp., associated with *Aucella piochii* Gabb, which later species has been found also on the north side of the valley. No invertebrate species has yet been found indicating the presence of any older Knoxville beds in either the Berryessa or Pope Valley, but on the contrary all these areas contain evidence of belonging to the Newville group and are overlain by beds of the lower Shasta series.

All these facts, easily verified, show that the Newville group extends to the west of the principal trough to which the older Knoxville groups are limited, and in these

areas it rests discordantly upon older rocks of the Klamath complex, including serpentine. Beds belonging to the Newville group extend to the west of Pope Valley in the vicinity of the old Aetna quicksilver mine, where they rest in part upon serpentine. On the south side of Pope Valley, these Newville beds rest discordantly upon a thick sequence of red, thin-bedded cherts that appear to be assignable to the Franciscan series and extend along the Pope Valley-Rutherford road for a considerable distance, with a strike and dip distinctly different from those of the Newville beds occupying the areas of Pope Valley. These conditions are repeated in many other areas of overlap in which Knoxville beds have been recorded.

Mount Diablo.—On the north side of Mount Diablo, between the branches of Bagley Creek, Knoxville strata having an exposed thickness of about 4,000 feet dip northward at a moderate angle and are overlain on the north by Cretaceous beds. It was probably here that the holotype of *Aucella piochii* Gabb was found. Near the same point Gabb seems to have obtained a perisphinctid species, near *Aulacosphinctes stantoni*, nov., though he did not mention it. The specimen is in the collections of the Academy of Natural Sciences at Philadelphia, among other specimens from this locality. In the dark shales outcropping on Bagley Creek there are many calcareous lenses containing well-preserved fossils, chiefly species of *Aucella*, but with a few other types. From these shales C. C. Church and the writer collected the following Knoxville species:

Aucella piochii Gabb,
Aucella russiensis Pavlow,
Aucella krotovi Pavlow,
Aucella stantoni Pavlow,
Aucella hyatti Pavlow,
Aucella fischeri (d'Orbigny).

Since all these species have been collected by the writer at a locality (Loc. 28,037, Calif. Acad. Sci.), in the Newville group in western Glenn County, associated with many other species diagnostic of Tithonian horizons in Europe, as shown by Pavlow and also by C. Burckhardt (1930), the locality at Mount Diablo, without evidence to the contrary, should be assigned to the same horizon. In the environs of Mount Diablo are other exposures of similar beds, all of which are assignable to the Newville group (Tithonian).

The shales which characterize these beds rest directly upon or against pre-Knoxville formations, as described by Turner (1891) and confirmed by others, including the writer. As will be seen later these areas represent an overlap of the Newville group upon the pre-Knoxville basement rocks of this area, similar to that found about the Berryessa Valley, and in other areas to be described later.

Berkeley Hills.—In this area stratigraphic conditions quite similar to the above are found along the west flank of the hills and in their southward extensions near Lake Chabot and south of Hayward. In the northern part of Berkeley, Knoxville beds are overlapped by Lower Shasta conglomerate, in which are boulders containing *Aucella piochii* Gabb and *Belemnites* sp., overlain by sandstone containing *Aucella inflata* Toula, *Balanus* sp., *Mytilus* sp., and shell breccia, as shown by the writer (1938).

Farther south, on the border of Sequoia Park, Oakland, Durrell discovered a small area of dark Knoxville shale enclosed between masses of serpentine, which shale

carries species of *Aucella*, including *Aucella russiensis*, *Aucella tenuicollis*, *Aucella subinflata* Pavlow, and other Newville species found in western Glenn County. Still farther south, a mile north of Lake Chabot, similar dark shales, with a near basal conglomerate and sandstone, overlie thin-bedded siliceous chert, from which they dip steeply to the south. From the sandy shales near the base of the Knoxville beds at this place Durrell and the writer collected the following species:

Aucella hyatti Pavlow,
Aucella stantoni Pavlow,
Aucella subinflata Pavlow,
Pentacrinus sp.,
Terebratula cf. *californica* Stanton,
Solemya cf. *S. occidentalis* Stanton,
Ophioglyphia? sp. (brittle star).

From dark concretionary shales about 1,200 feet lower in the section, R. L. Rist and the writer collected *Aucella piochii* Gabb, *Aucella stantoni* Pavlow, *Perisphinctes* sp., and probably a berriasellid species. This fauna also represents a Tithonian horizon and is referable to the Newville group of the Knoxville series.

The pre-Newville formations occurring along the west border of the Berkeley Hills, or from Mount Hamilton north to Marin County or farther, including siliceous cherts, are believed by many conservative writers to antedate the Nevadan orogney and the development of the Great Valley trough.

Diablo Range.—Areas of Knoxville strata appear at intervals along the east flank of the Diablo Range, southeast of Mount Hamilton, not all of which can be mentioned here. The strata of the Knoxville lie upon or against older rocks of various types, including siliceous cherts, sandstones, and pseudometamorphic types, basic igneous rocks, serpentine, and others not yet well studied. Of the Knoxville series only two areas can be mentioned, though others have been noted by Brewer, Whitney, and later writers that should not be overlooked.

On Quinto Creek (sec. 3, T. 9 S., R. 7 E.) are found dark shales, from which Bennison and others have collected a number of Knoxville fossils, including *Aucella stantoni* Pavlow, *Aucella krotovi*, *Aucella attenuata*, nov., a small form of *Oppelia* (*Streblites*), and other forms. Similar Knoxville beds outcrop near the head of Waltham Creek, Fresno County, where they are overlain unconformably by Paskenta conglomerates.

From the Knoxville beds on Waltham Creek Taliaferro collected *Aucella hyatti* Pavlow, *Aucella stantoni* Pavlow, *Aucella fischeri* (d'Orbigny), and a well-preserved fragment of *Perisphinctes* sp. From the overlying conglomerates he obtained a fine example of *Neocomites neocomiensis* (d'Orbigny), *Acroteuthis macarthyensis* Anderson, *Aucella crassa* and *Aucella andersoni* Pavlow, and other Paskenta forms. All the Knoxville species so far collected from the Diablo Range appear to be assignable to the Newville group, and no species yet found seem to indicate an older group.

Nipomo quadrangle.—Taliaferro (1943, p. 194–200) has published an account and map of a small Knoxville area, containing less than 4 square miles, in the Nipomo quadrangle, southern San Luis Obispo County. From his account, rather than from his map and section, the area appears to be one of unusual complexity, even though small. From the Knoxville shales included in the area Taliaferro collected a number of invertebrates, some of which were seen by the writer. The thickness of the beds assignable to the Knoxville series can hardly exceed 5,000 feet, but if the basalt of

the group were excluded the thickness would be somewhat less. The fossils appear to have been found at two levels in the sequence, between which is an interval of 1,000 feet or more. The fossils, a list of which is given in another place, were given to Crikmay for identification and determination as to age. By his determination (1932) they included three forms specifically named (one new), and six named only generically. However, all except the new species represent generic types known from the Newville group of the Knoxville in western Glenn County, where similar forms have been collected (Loc. 28,037, Calif. Acad. Sci.). Accepting Crickmay's determination of their age as Tithonian, it appears that the Knoxville series contains at top and bottom some reddish, chertlike beds, not before recognized. Doubtless this view is well founded, although the term "radiolarian chert" is subject to question as being exceptional, and further evidence would be helpful, particularly if the author designs to imply that it affords proof of a Franciscan age, which would be truly an "unorthodox" view of the matter.

Santa Ynez region.—Kew (1919) discovered Knoxville beds on the upper branches of the Santa Ynez River, Santa Barbara County, resting unconformably upon Franciscan rocks and overlain by a conglomerate of Cretaceous age, as was shown later. Nelson (1925) later described this occurrence in greater detail, giving the maximum thickness of the "Knoxville" as 5,000 feet. From the basal beds near the river he obtained *Aucella piochii* Gabb "in large numbers . . . east of Gibralter Dam". He appears to have found evidence of disconformity here between the Knoxville and Paskenta beds, concerning which he says (in part, p. 342–343): "From the occurrence of both *Aucella piochii* and *Aucella crassicollis*, it is inferred that the Knoxville as mapped, includes both the lower and upper divisions recognized elsewhere in California". To the present writer it appears evident that "the upper portion of the group" refers to the Paskenta group of the Shasta series, since it contains *Aucella crassicollis* Keyserling, characteristic of this group. Only the lower portion of Nelson's "Knoxville group" is correctly referable to the Knoxville series, from which the upper portion is separated by a "heavy conglomerate", described by Kew, from whose account Nelson (p. 342) quotes. There is little evidence given by either Kew or Nelson as to what part of the Knoxville series is described by these accounts, although neither of them gives any evidence of the presence in this area of either the Elder Creek or the Grindstone group; there is some evidence in the accounts of both Kew and Nelson that the "Lower Knoxville" beds appear more correctly to refer to the Newville group of the present interpretation. In this view the wide expansion of the Newville group already shown extends south to the Santa Ynez River (or Range). Nelson shows on his map of the area, and in his column (Pl. 45) and section (K-L, Pl. 47), something of the extent and thickness of the "group", indicating that it may have a thickness of 5,000 feet, of which at least half should refer to the Newville group of the present paper.

Other Knoxville areas.—Various scattered areas of Knoxville strata lie within the Great Valley or in its environs, trending to the north or south. Not all of them represent the same horizons. In many areas only the Newville group is found, resting upon pre-Knoxville terrains. This appears to be the case in the Wolf Creek district, north of Grants Pass, Oregon, where *Aucella piochii* Gabb has been found, and in

the lower portion of the "Myrtle formation" in Douglas County, as described by Diller (1908a), and in scattered areas in California. Such scattered areas have probably not all been recognized in California, Oregon, or Washington, since criteria for the purpose are not yet well known.

Fossil plants.—Reviews of this subject have been given by Diller (1908a) and by Knowlton. To Knowlton we are indebted for the lists of fossil plants contained in both reviews and for an interesting analysis of the Jurassic Flora of Oregon, concerning which he says in part (1910) that:

> "[it] is everywhere of true Jurassic age, that it is practically never found in association with the acknowledged Cretaceous flora, and finally, that the line between the Jurassic and Cretaceous of the region is to be drawn through the upper part of Knoxville and not at its base".

It should be pointed out that the term "Knoxville" in this text is not that of the present paper but refers to an older interpretation of the word.

We may accept the account of an important locality described by Diller—namely, that of Buck Peak, near Riddle, Oregon—as representing many, though not all these areas, since it appears that some of his localities are doubtless within the limits of the Lower Cretaceous. Overlying the plant beds at Buck Peak are other important beds, of which Diller says, in part (1908a, p. 373): "The summit of Buck Peak is conglomerate and sandstone containing the characteristic Myrtle (Knoxville) forms, *Aucella piochii* and *Aucella crassicollis* . . .".

The plant-bearing beds lie about 1,200 feet beneath the conglomerate at the summit of Buck Peak. Concerning these forms of *Aucella* it may be said that, should it be found later that *Aucella crassicollis* occurs only in the matrix of the conglomerate and *Aucella piochii* only in transported blocks, as is often the case in California, we may believe that the conglomerate at Buck Peak and vicinity marks the base of the Shasta series and accordingly may afford a clue for the division of the "Myrtle formation" in accord with that of the earlier so-called "Knoxville" in the Great Valley of California, and in accord with the suggestion of Knowlton above quoted.

The habitus of each of the foregoing species of *Aucella* is so characteristic, one in the Knoxville and the other in the Shasta series, that whenever both are found in the same stratum care should be taken to ascertain the manner of their association.

Both Diller and Knowlton have referred to the plant-bearing beds in the Cretaceous and "Knoxville" on the west border of the Sacramento Valley, and within the drainage areas of Trinity River, California, and of Elk River, Oregon. On the west border of the Sacramento Valley, these plant-bearing beds occur within the delta areas of both the Knoxville (Jurassic) and the Shasta (Cretaceous) series. Knowlton believed that he could discriminate between plants of the Jurassic and those of Cretaceous age, and he appears to have succeeded well in doing so, though not in all cases. Exceptions may be taken to his use of the term "Jurassic Flora of Oregon", in which he included the strata and areas of Big Bar and of Rattlesnake Creek, the latter near Forest Glen, Trinity County. Neither of these areas can be shown by their molluscan faunas to be referable to the Knoxville series, or even the Newville group. The area near Big Bar contains molluscan fossils that relate it to the Paskenta group, rather than to an upper Knoxville horizon, as shown by the writer (1938, p. 35, 50), and the same view attaches to the areas near Forest Glen, as already shown. The Jurassic sediments known on the west border of the Sacramento Valley and in the

adjacent Coast Range areas are those referable to the Newville group, and the same may also be said of correlative strata in western Oregon—namely at Buck Peak. Any stratigraphic group containing criteria indicating a late Jurassic age should probably be referable to the Newville group of the Knoxville, as already shown.

An analysis of Stanton's statements (1895, p. 15) shows clearly that the plants listed by him, as identified by Fontaine, were taken from a horizon well within the limits of the Newville group. The same assignment can now be made for the invertebrate species listed by Stanton (1895, p. 17) from the point 3 miles northwest of Paskenta. The plants listed by Diller (1908a, p. 385) from Loc. 37 on McCarthy Creek clearly came also from the Newville group of the Knoxville.

In Diller's section of the Buck Peak locality (1908a, p. 374) in Oregon, whence came the plants referred to as Jurassic (p. 373), it appears that they were collected from a horizon, 1,200 feet beneath the conglomerate at the summit of the mountain, containing *Aucella piochii* Gabb. These plant-bearing beds may also be referred to the Newville group, as representing an overlapping extension of marine deposits quite similar to those seen in the extra-lateral spread of the same in California, as already indicated. However, fossil wood, probably *Sequoia*, has been found by the writer at the base of the Grindstone group west of Blue Canyon, in the Elder Creek area, although much more occurs in the Newville group, east of this canyon, and higher in the section on the Oake's place.

FAUNAS OF THE KNOXVILLE SERIES

GENERAL CONSIDERATIONS

The combined known fauna of the Knoxville series in its type areas is not large, although it is evident from fragmentary remains in the collections, and as seen in the field, that it is still incompletely known. Insofar as here represented it contains three diverse major elements that specifically appear in about equal numbers—namely, ammonoids, belemnoids, and pelecypods. There are few known types of either echinoids or brachiopods, the lack of which may be attributed to the nature of the shores, to the character and temperature of the water, or to extraneous conditions that prevented their arrival. The following synopsis gives the relative proportions of the several classes of invertebrates found in the combined fauna:

	Member of species	
Brachiopoda	1	(0 new)
Gastropoda	6	(2 new)
Pelecypoda		
Aucellae	19	(1 new)
Other types	12	(5 new)
Ammonoidea	22	(17 new)
Belemnoidea	19	(18 new)
Total number	79	(43 new)

This assemblage of species has been collected largely from two widely separated portions of the general column: from near its top, Tithonian in age; and near its botton, Portlandian in age. The older portion has been collected from the lower

4,600 feet. The younger and larger portion (specifically, 85 per cent) was found within 4,000 feet of the top of the series, in other words within the upper fourth of its stratigraphic column. This relatively large number of species entering the column near its summit suggests some unusual diastrophic event as its cause, such as a widespread tectonic disturbance that resulted in physiographic changes permitting migrations hither from other regions and bringing into this basin new faunal elements (ammonoids and belemnoids). From what source, or sources, this invasion came may be problematical, although many similar types are known in northern Europe, Russia, and in England.

Probably the succession of conglomerates and coarse sandstones found in the Grindstone group mark an interval of rapid erosion due to a progressively increased elevation of the hinterland, and this view accords with that of a disconformity between the Elder Creek group and the Grindstone group, as already noted. To what longitudinal extent this diastrophism was felt is not yet known, although the later faunas in the Elder Creek group indicate connections with northern Europe.

In a similar manner it might be shown that the faunas of the Newville group have in their belemnoid elements strong relations with contemporaneous faunas of England and of western Europe.

It is too early to enter into detailed discussions of this subject until more complete faunal data from the more northern latitudes are available, although the resemblances shown by Pavlow (1907) in the aucellan and other faunas in the Russian and Californian Mesozoic reflect adequate seaways of communication, as was long before pointed out by Lahusen, Hyatt, J. P. Smith, and others, and summarized by Stanton (1895, p. 40, 41). Many of the views of these earlier writers apply to the present revised views and limitations of the Knoxville series as a whole, and the revised terminology applied to the succession in no way invalidates the general concepts of these writers, nor their contributions, though it may alter or emend them. The summary discussion of the distribution of the genus *Aucella* by Stanton (1895) is an inspiring chapter upon the physical geography of the time and upon the wanderings of this genus and suggests as much for other genera.

By the additional material from the type areas of the Knoxville obtained by Sokolow and Pavlow, the number of Knoxville species is greatly increased, but the percentage of those that continued into the California Cretaceous has remained unchanged. Of the 80 or more invertebrate species listed or known at the present time, less than 10 have been found in the Shasta series, and some of these may be regarded as being only similar forms, not as proved descendants from any found in the Knoxville series. A few pelecypods only may be identified tentatively as occurring in both series.

CHRONOLOGICAL DIVISIONS

General statement.—The chronological features of the Knoxville series have already been indicated. The bases of its divisions are primarily diastrophic and physical, rather than faunal, and are marked by physical changes seen in the stratigraphic column when traced throughout its basin of deposit, rather than by local and obscure details which often exhibit confusing vagaries. The overlaps of stratigraphic units,

one upon another, or upon the basement complex, are of prime importance as indices of physical changes and of events that have controlled the course of faunistic changes throughout the record of Knoxville time, as in other periods of earth history.

The stratigraphic column of the series readily divides itself into three principal groups, which chronologically fall into two chief divisions, earlier and later, and which are translatable into two stratigraphic divisions, a lower and an upper. These divisions are not of equal stratigraphic volume, although in other respects they may be of equal importance. As these faunistic changes have been developed in the wake of physical events they are to be regarded as evidence of such, and serve as indices of the facts, which of course are of primary importance and value in the record of events.

Adopting the views of Burckhardt (1906–1930) and of Spath (1927–1934) the chronological succession in later Jurassic time in many regions includes three major units—namely, Upper Kimeridgian, Portlandian, and Tithonian. On the West American Coast, as represented in the Great Valley trough, if Kimeridgian strata exist at all, they are deeply buried or appear only in the supposed barren beds at the base of the Elder Creek group. The uppermost group of the succession is wholly of Tithonian age and in general makes up about one-third of the series in its thickest exposures. We may unite the Grindstone with the Elder Creek group as representing Portlandian time, and the former may be regarded as constituting an upper Portlandian stage, and insofar as known this assignment seems satisfactory and may be tentatively adopted.

Portlandian epoch.—Insofar as known the Elder Creek fauna is limited to a stratigraphic range of 2,200 feet near the central part of the group and there occupies about one-third of its general volume, beginning about 1,200 feet above its base. The earliest faunal elements, already mentioned, consist of a few species—namely, *Aucella sollasi* Pavlow var., *Aucella gabbi* Pavlow, and some doubtful types. These were collected on the South fork of Elder Creek near the Pellows homestead. On Toms Creek, at about the same horizon, were found *Belemnopsis californica*, nov., and *Belemnopsis tomsensis*, nov., and a small species of *Aucella* resembling *Aucella bononiensis* Pavlow.

In this area about 1,000 feet higher in the section, and half a mile farther east (Loc. 29,694 Calif. Acad. Sci.), near Hull's gate, R. L. Rist and the writer collected a considerable aucellan fauna, including *Aucella gabbi* Pavlow, *Aucella elderensis*, nov., *Aucella gracilis* Pavlow, and a fragmentary example of *Durangites* aff. *D. vulgaris* Burckhardt. About 1,000 feet higher in the section, and a mile or more farther south Rist collected the holotypes of *Kossmatia tehamaensis*, nov., and *Pecten (Chlamys) risti*, nov., and species of *Aucella*

Farther north, a mile east of the Kleinsorg chromite mine, situated in sec. 27, T. 25 N., R. 7 W., in approximately the horizon just described, Rist and the writer collected *Kossmatia kleinsorgensis*, nov., *Aucella* n. sp. A, and *Belemnites* sp. It was in this area that the holotype of *Kossmatia dilleri* (Stanton) was found.

Spath (1923, p. 306) has mentioned the occurrence of *Kossmatia*, *Durangites*, and Steueroceras in "Knoxville" strata in California, but the basis of his statement is not clear. *Steuerococeras* is known only from Tithonian horizons.

From the Portlandian of north-central Mexico Imlay (1939, Table 8) has listed as many as 10 species of *Kossmatia* and 12 species of *Durangites*, forming its principal faunal elements. Burckhardt (1930, Table 6) places the beds with *Kossmatia* in the

TABLE 1.—*Proposed subdivisions of the Knoxville series in its typical areas in California**

TITHONIAN	Newville group	Protacanthodiscus crossi, nov.	Aulacosphinctes taffi, nov.
		Aulacosphinctes reedi, nov.	Aulacosphinctes jenkinsi nov.
		Berriasella storrsi (Stanton)	Aulacosphinctes? diabloensis, nov.
		Phylloceras knoxvillense (Stanton)	Substeueroceras stantoni, nov.
		Phylloceras glennense, nov.	Phylloceras timothyi, n. name
		Cylindroteuthis tehamaensis (Stant.)	Cylindroteuthis glennensis, nov.
		Cylindroteuthis klamathonae, nov.	Cylindroteuthis porrectiformis, nov.
		Cylindroteuthis clavicula, nov.	Belemnopsis berryessae, nov.
		Bochianites glennensis, nov.	Acroteuthis? watsonensis, nov.
		Aucella trigonoides Lahusen	Rhynchonella schucherti Stanton
		Aucella piochii Gabb	Aucella okensis Pavlow
		Aucella stantoni Pavlow	Aucella occidentalis, nov.
		Aucella terebratuloides Lahusen	Inoceramus scotti, nov.
		Cerithium paskentaensis Stanton	Inoceramus stantoni, nov.
		Iteria californica, nov.	Cardiniopsis unioides Stanton
PORTLANDIAN	Grindstone group	Aulacosphinctes? colusaensis, nov.	Hibolites wilburensis, nov.
		Aucella aff. A. pallasi, Keyserling	Aucella aff. A. bononiensis Pavlow
		Aucella sollasi Pavlow	Aucella cf. A. mosquensis (von Buch)
		Aucella russiensis Pavlow	Aucella hyatti Pavlow
	Elder Creek group	Kossmatia dilleri (Stanton)	Kossmatia kleinsorgensis, nov.
		Kossmatia tehamaensis, nov.	Belemnopsis californicus, nov.
		Durangites aff. A. vulgaris Burckhardt	Belemnopsis tomsensis, nov.
		Aucella gabbi Pavlow	Aucella n. sp. A
		Aucella cf. A. mosquensis (von Buch)	Aucella cf. A. sollasi Pavlow, var.
		Pecten (Chlamys) risti, nov.	Belemnopsis sp. indet.
		No fossils have been found in these beds, 1,200 feet in thickness	

* Blank spaces indicate only that no fossils other than *Aucella* have been found.

"Upper Portlandian", above the horizon with *Proniceras*, a genus not yet found in the typical areas of the Knoxville in California.

The Grindstone group has a maximum thickness of about 5,400 feet, consisting chiefly of coarse detritus, conglomerates, sandstones, and sandy shales, the last confined largely to the upper part of its sequence. The group is stratigraphically distinct from both the Elder Creek and the Newville groups, although faunally it is undoubtedly related to both, being dominated by *Aucella*.

In crossing the upper part of its sequence one is impressed by the uniform succession of alternating thin-bedded sandstone and sandy shales, the latter often richly supplied with species of *Aucella*, but with few other molluscan genera. One species of this genus that is locally abundant is elongated and rather large and is either identical with or closely akin to *Aucella russiensis* Pavlow, abundant also in the latest group.

The stratigraphic position of the beds exposed at Blue Canyon, west of the Oake's home, and their lithological succession indicate that these beds represent the upper portion of the Grindstone group, here overlain by the Newville group.

Pavlow (1907, p. 84) lists as middle Portlandian ("Portlandian moyen"), *Aucella sollasi* Pavlow, *A. dilatata*, *A. subovalis*, *A. stantoni*, *A. hyatti*, *A. russiensis*, *A. obbreviata*, *A. gabbi* all by Pavlow, and *A. fischeriana* d'Orbigny, 75 per cent of which species have been found in the Grindstone group in its typical areas, and in the strata exposed at Blue Canyon, at the top of the Grindstone section.

From the foregoing summary it is evident that the upper part of the Grindstone group is assignable to a (probably middle) Portlandian horizon, leaving a chronological hiatus between it and the exposures of the next group of the Knoxville series. How much of the upper Portlandian sequence is missing from the exposed sections is not known, but that the following group of the series is disconformable upon the Grindstone group appears to be clearly shown both stratigraphically and faunally. However, further evidence is to be found in the following pages.

Tithonian epoch.—The Newville group, already shown by its areas and its stratigraphy to be separable and distinct from the preceding group of the series, is also chronologically distinct, as shown by its faunas. It is characterized by three classes of Mollusca—namely, ammonoids, belemnoids, and pelecypods (Aucellas)—that entered the succession rather abruptly, few of the former two classes having been found in the preceding groups. No faunas are known in the series that can be regarded as transitional between those of the Elder Creek or Grindstone group and those of the Newville group, especially among its cephalopods, of which there are many in the later group. No gastropods, and few pelecypods other than Aucellae, are known in the older groups, though they are numerous or frequent in the Newville group, especially in favored localities. These faunal changes appear to have followed the profound subsidence that initiated the wide overlaps of the Newville group (or epoch) upon the older groups and upon the adjacent rocks of the Klamath complex.

The Newville group has a general thickness of about 4,600 feet and is marked by a fauna sufficiently distinctive in containing *Substeueroceras*, *Aulacosphinctes*, *Virgatosphinctes*, *Protothurmania*, numerous belemnoids (*Cylindroteuthis*), *Bochianites*, and many distinctive forms of *Aucella*, not known in the older groups of the series. Stanton has pointed out a number of representative localities at which the faunas of this group are well illustrated, including the following (a, b):

a. A point 3.5 miles northwest of Paskenta, described by Stanton (1895, p. 16, 17) as containing *Rhynchonella schucherti* Stanton, *Turbo paskentaensis* Stanton, *Aucella piochii* Gabb, *Solemya occidentalis* Stanton, *Turbo paskentaensis* Stanton, and others.

b. A locality northwest of Cooper's place on the South fork of Elder Creek, at which he obtained the holotypes of *Phylloceras knoxvillense* Stanton, *Berriasella storrsi* (Stanton), and *Cylindroteuthis lehamaensis* (Stanton).

Other localities have since been discovered by the writer (c), by Gregerson and Burger (d), and by Taliaferro (e), each of which has supplied important additions to the faunas of the Newvillè group. Exhaustive collections have not been made from any of the localities mentioned, but each has contributed to the general fauna from localities both within and outside the Great Valley. Many other localities could doubtless be added.

c. Loc. 28,609 (Calif. Acad. Sci.), on the Alder Springs road, 3.5 miles north of the Winslow bridge, from which were collected the following:

Perisphinctes sp. indet.
Virgatosphinctes? sp. indet.
Lytoceras sp. indet.
Fossil wood
Pecten (*Syncyclonema*) aff. *P. concentricum* Koch
Inoceramus scotti, nov.
Aucella russiensis Pavlow
Aucella piochii Gabb

d. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, 6 miles north of the Winslow bridge; dark shales exposed near the Ellis gate, 400 feet in thickness, and identifiable on Grindstone Creek, half a mile to the south; containing the following species of invertebrates:

Lytoceras aff. *L. liebigi* Oppel
Lytoceras cf. *L. exoticum* Oppel
Lytoceras huberti, n. sp.
Phylloceras knoxvillense Stanton
Phylloceras glennense, n. sp.
Spiticeras aff. *serpentinum*
Substeueroceras stantoni, n. sp.
Aulacosphinctes reedi, n. sp.
Aulacosphinctes taffi, n. sp.
Aulacosphinctes? diabloensis, n. sp.
Berriasella storrsi (Stanton)
Cylindroteuthis tehamaensis (Stanton)
Cylindroteuthis glennensis, n. sp.
Cylindroteuthis clavicula, n. sp.
Cylindroteuthis klamathonae, n. sp.
Cylindroteuthis knoxvillensis, n. sp.
Cylindroteuthis porrectiformis, n. sp.
Bochianites glennensis, n. sp.
Distoloceras sp. indet.
Crioceras sp. indet.
Inoceramus scotti, n. sp.
Inoceramus stantoni, n. sp.
Aucella piochii Gabb
Aucella hyatti Pavlow
Aucella stantoni Pavlow
Aucella subinflata Pavlow
Aucella fischeri (d'Orbigny)
Aucella tenuicollis Pavlow
Aucella russiensis Pavlow
Aucella okensis Pavlow
Aucella subokensis Pavlow
Acroteuthis watsonae, n. sp.
Cerithium paskentaensis Stanton
Itieria californica, n. sp.

e. Nipomo quadrangle, southern San Luis Obispo County, from which Taliaferro collected the following species, as determined by Crickmay:

Protothurmannia rezanoffiana Crickmay
Berriasella cf. *B. calisto* (d'Orbigny)
Substeueroceras sp. indet.
Crioceras sp. indet.
Bochianites sp. indet.
Phylloceras sp. indet.
Lytoceras sp. indet.
Pachyteuthis? sp.
Aucella terebratuloides Lahusen

Crickmay (1932, p. 1–11) correctly referred this fauna to a Tithonian horizon, and most of the forms given in this list probably occur, partly under other names, at Loc. 28,037 (Calif. Acad. Sci.), or in its horizon in Glenn or Tehama County, or at other points farther south where beds of this horizon outcrop. As seen from the list given above the horizon in the Nipomo quadrangle is clearly within the Newville group, which according to the data given by Taliaferro (1943, p. 197) rests directly

upon Franciscan rocks, and with a corresponding unconformity, as in other cases of the wide expansion of the Newville group beyond its type areas, reaching from the Santa Ynez River north far into Oregon.

FAUNAL ASPECTS OF THE KNOXVILLE SERIES

The segregation of the Knoxville series from the strata included in the Lower Cretaceous Shasta series (1938) logically implies that it belongs within the limits of the preceding Jurassic system, as in truth it does, wherein it covers only its later chronological divisions—namely, the Portlandian and Tithonian, as already shown. Faunistically the series differs greatly from the preceding Mariposa beds, which are believed to antedate the Nevadan orogeny, as it does also from the succeeding Shasta series, as described by the writer (1938). In a synopsis of its faunas given in the early part of this paper a total of about 79 invertebrate species is recognized as characteristic of the series. Of these, 31 species (nearly 40 per cent) are pelecypods and are largely included in Myalinidae Frech. In the genus *Aucella* Keyserling is included a total of 19 species, most of them already described by Pavlow(1907). This genus occurs abundantly in each of the several groups, especially in the earlier two, and constitutes the prevailing faunal element in all that unites them into a paleontological unit, as appears to have been recognized by Becker (1888) in stating the limits of the series. Surely the genus constitutes the most important element in the fauna of the series as a whole, giving it character and unity throughout, as recognized by Smith (and Hyatt) (1895), by Stanton (1895), by Pavlow (1907), and later by various writers.

Few gastropods have been described from the series, nearly all by Stanton, and for the most part confined to the Newville group, which in the Great Valley they characterize almost exclusively. They are rare in the Portlandian groups and occur sparingly in Tithonian time. Fragmentary remains indicate that many species are undescribed.

Ammonoids, of which 22 species have been named, are largely confined to the Newville group and constitute its most distinguishing faunal feature, although none have been recorded from areas outside the Great Valley, except in its immediate environs, indicating their requirements of protected waters.

In the same enclosed basin belemnoids also found refuge from enemies that may have inhabited the open sea, and for the most part they were limited to a few genera only. In the Elder Creek group they were represented by the genera *Hibolites* and *Belemnopsis*. None have been found in the Grindstone group, whereas in the Newville group, as far as known, only *Acroteuthis* and *Cylindroteuthis* have been found. In the facts here given may be found a hint as to the seclusion of the Great Valley basin from the predatory inhabitants of the open ocean, which may have been numerous during Knoxville time. It is not now known whether vertebrate animals entered the basin during these times, although little trustworthy evidence has been found that they were excluded from it. Camp (1942) has described certain species of ichthyosaurs from the Diablo Range that may later be found referable to the Knoxville epoch, but of this there is no present proof.

In discussing the aspects and relationships of Aucellan species described by Eichwald (1871), Pavlow (1907, p. 80, 81) says, in part:

"Not having had opportunity to study the specimens of Aucella figured by Eichwald, trusting to his figures I believe that among the Aucellas he has figured, one can recognize the following species":

(*Aucella concentrica* Eichwald) = *Aucella orbicularis* Hyatt
(*Aucella mosquensis* Eich.—pars) = *Aucella rugosa* Fischer
(*Aucella mosquensis* Eich.—pars) = *Aucella bononiensis* Pavlow
(*Aucella mosquensis* Eich.—pars) = *Aucella pavlovi* Sokolow
(*Aucella palasi* Eichwald) = *Aucella mosquensis* (von Buch)

"In brief, it is the Lower Portlandian that is indicated by these forms".

We may note concerning the foregoing list of species that at least two, and perhaps three, of the forms have been found in the lowest beds of the Knoxville (Elder Creek group) in its type areas in the Sacramento Valley, California, although this may not be regarded as proof of a Lower Portlandian horizon in these areas. Martin (1926, opp. p. 270) gives a correlation chart in which he indicates that the upper part of the Naknek formation on the Alaska peninsula and on Cook Inlet may be regarded as Portlandian in age.

A review of the Kennicott formation of southern Alaska by Martin (p. 330–339) indicates that it may also include strata containing *Aucella*, "related to *Aucella pallasi* Keyserling", and fossil plants that Knowlton regarded as "Upper Jurassic". It has already been shown that equivalents of the upper part (Newville group) of the Knoxville occur in parts of southern Alaska. From various references to the "late Upper Jurassic" found in Martin's account it is understood that he referred to the equivalents here included in the correlation notes given above, although a precise parallelism of its parts with the groups of strata recognized in California may not now be possible. Concerning the Upper Jurassic deposits in this region Martin (p. 286) says in part:

"The Jurassic expansion of the sea reached its culmination in late Upper Jurassic time, when marine sediments were laid down in great thickness throughout the region south of the Alaska Range. . . . The area of the late Upper Jurassic marine sedimentation probably included all of south-central Alaska, and was sharply bounded on the north by the present line of the Alaska Range. . . .

"The late Upper Jurassic sea probably was directly connected with the cold water Upper Jurassic sea of northern Europe and Asia".

In these references to the "late Upper Jurassic", it is understood that Martin referred to strata equivalent to beds included in the Knoxville series, although an exact correlation of its parts with the groups of strata recognized in California may not now be possible.

CHRONOLOGICAL FEATURES

The invertebrate faunas of the Knoxville series are not large but are far from being completely known, and they may be regarded as essentially representative of the time occupied in the sedimentation of the series. They have been gathered from various levels in the general column, though chiefly from its lower and its upper quarters.

On the eastern border of its belt, representing its highest quarter, where inflowing tidal currents tended to maintain more uniform water conditions, larger and more

varied faunas doubtless existed, and such have been collected. On its western border the invertebrate faunas were restricted to areas and localities in which water conditions were favorable, or at least tolerable. Only on the western border of the trough are to be found the older faunas of the series, although these are probably not completely known. Fragmentary remains collected or seen in the field indicate the earlier existence of many types of invertebrates that cannot be described at present for lack of satisfactory materials. However, from the remains that have been collected from the Elder Creek group, its Portlandian relations and age appear to be evident from its cephalopods, with species of *Kossmatia* and probably of *Durangites*, and from the presence of *Aucella mosquensis* (Von Buch) and *Aucella bononiensis* Pavlow, thought by Pavlow to be early Portlandian. The cephalopods may be compared with *Kossmatia* and *Durangites* of central and northern Mexico, as illustrated by Burckhardt (1906–1930), or with their analogues in Europe. The same remark applies to the forms of *Belemnopsis* described from the Elder Creek group, as found on Toms Creek, stratigraphically not far above the exposed basal contact of the Knoxville. An analytical study of the Grindstone group indicates, though it does not prove, that this group also falls within the limits of Portlandian time. According to its fauna, with *Aucella sollasi* Pavlow, *A. stantoni* Pavlow, *A. hyatti* Pavlow, and *Aucella russiensis* Pavlow, it represents the horizon of *Virgatites virgatus*, or middle Portlandian ("Portlandian moyen").

The combined thickness of the two lower groups, the Elder Creek and the Grindstone, represents about 75 per cent of the series, whereas the thickness and time of the Newville group which is assignable to Tithonian time, occupies about 25 per cent of the whole. Between middle Portlandian and lower Tithonian there is probably a time hiatus.

DIASTROPHIC FEATURES

The succession of major events embraced in the Knoxville period began at the close of the Nevadan orogeny and the development of the Great Valley trough, which culminated in earliest Portlandian time, and from this point on events proceeded somewhat in the following order:

(1) The earliest sediments laid down in the Great Valley trough were deposited upon a floor of terrains that had been deformed by the Nevadan orogeny. This sedimentation probably began in early-middle Portlandian time and initiated the sedimentary succession named by Becker (1885; 1888) the Knoxville series. The earliest recognizable division of this series is here termed the Elder Creek group, and its time interval, the Elder Creek epoch. It is distinct from the succeeding sequence. Its faunistic features are marked by the presence of diagnostic cephalopod stocks (*Kossmatia*, *Durangites?*, and *Belemnopsis*) and by various types of *Aucella*. Its outcrops are almost wholly limited to the north of Toms Creek, southern Tehama County, extending but little to the south of it, being overlapped by the Grindstone group.

(2) The Elder Creek epoch was brought to a close by a definite uplift in its areas, the duration and spread of which cannot now be determined precisely, but the latter is indicated by an overlap of strata belonging to the next group that

extends upon the Klamath complex and by an almost complete faunal change, with the disappearance of certain cephalopods and of many types of *Aucella* that had been present during the Elder Creek epoch.

(3) The laying down of conglomerates and coarse sandstones, which constitute the Grindstone group, gives evidence of an overlap that spread its sediments somewhat to the west and upon the rocks of the Klamath complex, as seen on the slopes of Tedoc Peak and southward. This overlap and the distinctive character of its sediments afford evidence of an uplift in their source areas to the west, and probably also of subsidence in their areas of deposition to the east. The faunistic features of the Grindstone group, with the complete loss of cephalopods but the continuation of aucellan species of restricted types, indicate that important changes had taken place in the depths or other conditions of the water, though the closing steps of the epoch, with sandy shales, and insofar as known a scanty fauna, indicate subsidence and a deepening of water within the trough. Deposits of this group are not known south of Wilbur Springs, Colusa County. Its chronological position is that of the upper-middle Portlandian and accordingly relates the group to the preceding, notwithstanding its evidence of distinctness from the Elder Creek group.

(4) The increasing load upon the basin floor should have produced, and did initiate, subsidence within the trough during the later part of the Grindstone epoch, as shown by its sandy shales with only a scanty molluscan fauna, as compared to the conditions and faunas that followed. Little is otherwise known concerning the closing part of the Grindstone epoch, although there is convincing evidence in the faunistic changes that occurred in passing from this group to the next of a considerable time hiatus between the two groups. It is probable that an uplift on the Great Valley borders and an interval of erosion intervened, but of this no stratigraphic evidence is known.

(5) Subsidence in the Great Valley trough, and in areas beyond its limits, to the north (in Oregon), and to the south (in the Santa Ynez region), and to the west (Reiff and Morgan Valley), with the laying down of an important marine sedimentary sequence, the Newville group, bringing into the trough a large and varied faunal assemblage, with ammonites (berriasellids, *Aulacosphinctes*, *Phylloceras*), belemnites (*Cylindroteuthis*, *Pachyteuthis*), and Aucellae of distinctly Russian types that indicate the opening of more convenient channels of communication with northern and western Europe. This subsidence resulted also in a considerable longitudinal spread of the above mentioned faunas along the Pacific Coast, apparently extending from Alaska to Peru, or farther.

(6) The close of Knoxville time, with an uplift and erosion, and a subsequent overlap upon this series of heavy conglomerates, now in unconformable relation, as evidence of an unquestionable break in the succession between Knoxville and Lower Cretaceous (Paskenta) deposits in the Great Valley of California.

STRATIGRAPHIC FEATURES

The stratigraphic relations of the Knoxville series and its position in the Mesozoic column of California are seen in part in its basal and summit contacts in its type

areas. They are seen more clearly in the physical and faunistic contrasts when compared with older or younger terrains in the Great Valley wherein the series has its only complete development. Its relations to the overlying Shasta series have already been shown by the writer (1938) as one of unconformity, evidenced in many areas by heavy beds of conglomerate at the base of the Shasta series. In like manner in many areas the basal beds of the Knoxville series contain evidences of having been laid down in depositional contact upon a floor of older rocks, and thus in unconformable relation to them, as already indicated. In its type areas, as in most others, these deposits are found upon the borders of the Great Valley basin in low altitudes, and never at great elevations above the sea or above the valley floor. In this respect, as well as in lithological character, they contrast strongly with their neighboring terrains, so that their basal border is readily mapable with great accuracy, even where contacts are not well exposed or are even concealed by terrace deposits that overlap the contact. However, in most areas the line of contact at the base of the Knoxville is clearly exposed, and in others it is well indicated, either by abrupt lithological changes, by changes in soil conditions, or by the vegetation growing upon the soil.

When the basal border of the Knoxville series is traced southward from Beegum Creek, northwest Tehama County, its lowest exposed beds are seen to rest directly upon or against older rocks of various types (crystalline schists, Paleozoic clastic rocks, greenstones, peridotites, metamorphic rocks of various classes), some of which are probably of early Mesozoic age. In most, if not in all, areas a relation of unconformity appears evident, either in abrupt lithological changes or in the topography or in the vegetation and soil conditions or in the strike or attitude of the formations themselves. In some areas Pleistocene terraces lying against the rocks of the Klamath complex and upon the upturned strata of the Knoxville obscure the contact for a limited distance, but without concealing the locus of the Knoxville contact. To most observers the topographic aspect of the Knoxville series as contrasted with that of the Klamath complex plainly indicates their relationship, and different but clearly legible conditions of contact are found at the top of the series, as already stated. However, south of Wilbur Springs, Colusa County, no exposures of the older groups of the series are found.

CORRELATIVE DEPOSITS

General statement.—Only partial notes can be attempted here bearing upon the more important deposits bordering the West Coast and in the Cordilleran regions that seem probably to be correlative with the Knoxville series, or with some part of it, concerning which the pertinent facts have been gathered from published accounts, although the writer has had personal contact with some of them.

Oregon areas.—A review of published accounts of Mesozoic formations in southwest Oregon reveals some evidence that Knoxville beds, in the sense here used, occur to only a limited extent, in fact much less than might be expected, in view of the known Lower Cretaceous deposits in more favored areas. This appearance may be due to a lack of field search for paleontologic criteria pertaining to late Jurassic deposits in California and Oregon during the past decades. The frequent references to "Knox-

ville" beds found in these accounts are often confusing to students of West Coast geology.

Diller (1907; 1924) used the term "Myrtle formation" to include older beds with the Shasta, and possibly also some Jurassic Knoxville beds, as here understood. Later readers of these papers find difficulty in deciding to which of these series Diller refers in his use of the terms "Myrtle" and "Knoxville", which are sometimes used in their earlier sense. Also his references to *Aucella piochii* Gabb are not quite clear, since they were made prior to the publication of Pavlow's paper 1907. It was pointed out by the writer (1938) that much of the "Myrtle formation" belongs to the lower part of the Shasta series, although a part may be older and may be of Knoxville age. Concerning the lentils of "Whitsett limestone" in the Dillard area, Diller (1907, p. 419) says in part: "The occurrence of limestone in the upper part of the Knoxville in the Dillard area is not wholly exceptional, for it occurs at that horizon in several places along the west side of the Sacramento Valley in California".

This view was not accepted by the present writer (1938, p. 43), and it was shown that the limestone referred to in the California localities belongs to the lower Shasta (Paskenta) horizon near its base. In the Dillard area, as discussed by Diller (1907, p. 416), if a line be drawn from southwest to northeast connecting generally the outcrops of the "Whitsett limestone", it will be found that nearly all localities indicated as containing *Aucella crassicollis* lie south of it, and those with *Aucella piochii* Gabb lie north of it. However, this is not quite conclusive as evidence. Briefly, if strata representing the Knoxville series occur in this region, they probably are referable to the Newville group, as has already been shown for those of Buck Peak, near Riddle, farther south.

British Columbia.—Crickmay (1930a) has described Upper Jurassic formations in the vicinity of Harrison Lake, British Columbia, though he gives only meager stratigraphic data concerning them. He refers many of the species he collected here to a Lower Cretaceous horizon, although certain forms figured by him as such (*Aucella cascadensis*, *Cylindroteuthis baculus*, and others) closely resemble species from the Newville group (Tithonian) in California. In his brief stratigraphic note concerning this district Crickmay adds (p. 37): "The lower part of the Cretaceous series consists of a basal conglomerate overlain by gray sandstone totaling 1,200 feet in thickness".

As conglomerates make up a large part of the Grindstone group in the Knoxville series in its typical areas in California, the resemblance of this part of his "Cretaceous series" to the upper Knoxville (Grindstone and Newville) is thereby somewhat increased.

Alaska.—Earlier writers have recognized the boreal character of the aucellan faunas in the late Mesozoic (Knoxville in California), and Pavlow (1907) has shown near specific relationship of these stocks with those known in similar horizons in Russia. Such relationships appear also among the cephalopods, especially among belemnoids.

It could be inferred from such facts that equivalents of the Knoxville series should be found in some of the larger valleys of Alaska, and evidence that such have been found appear in accounts given by the U. S. Geological Survey covering southern

Alaska and the Alaskan peninsula, although detailed information has not been published. Stanton and Martin (1905), in describing the Naknek formation on the Alaska peninsula and on Cook Inlet, mention many species of *Aucella*, including *Aucella pallasi* and *Aucella bronni*, found in the lower Volga beds of central Russia. Under the heading "Lower Cretaceous" (p. 407), there is mention of *Aucella piochii* Gabb, a species well known in the Newville group in California and Oregon.

Rocky Mountains.—The much-discussed Morrison formation, extending from New Mexico northward through Colorado, Utah, Wyoming, and Montana, from which most of the dinosaurs of the West have come, as shown by Schuchert and Dunbar (1941, p. 328–33), includes strata correlative with the Portlandian and Kimmeridgion epochs of England and western Europe. Concerning the age of this formation these authors say, in part:

> "A comparison of the dinosaurs of the Morrison with those of the Jurassic and Cretaceous of Europe, however, brings out rather convincing evidence of Jurassic affinities (especially among the Stegosauria), and this is supported also by a comparison of the mammals. Curiously the best evidence on the age of the Morrison is found nearly half-way around the Earth, in East Africa, where there are beds bearing dinosaurs closely like those of the Morrison interbedded with marine zones carrying undoubted Jurassic ammonites".

This correlation of the Morrison formation in part with the Portlandian of England indirectly includes the Knoxville series of the Pacific border, which covers the same chronological epoch, and accordingly extends its correlation to other parts of the Cordilleran regions of western America and to Europe, Asia, and Africa.

Texas.—Concerning the Upper Jurassic of the Malone Mountains in western Texas, Albritton (1937, p. 1763) correlates a portion of the Malone formation with the Upper Jurassic beds of San Pedro del Gallo, Durango, which have been referred by Burckhardt (1930) to Portlandian (and "upper Portlandian") horizons, and thus indirectly correlated with the Knoxville series on the West Coast (beds with *Kossmatia dilleri* (Stanton), and with *Kossmatia kleinsorgensis*, nov.). But Albritton further says in part: "Lower portion unfossiliferous—may belong in part to lower zones of the Portlandian".

Concerning the epoch following the Nevadan orogeny, it is interesting to note the continental aspect of the Morrison formation lying between the longitude of Malone and north-central Mexico on the east, and that of the Knoxville series on the west, thus indicating an epoch of uplift and land conditions in the Rocky Mountains at the north during Portlandian and Tithonian times, and conditions of submergence on both flanks of the western Cordillera.

Japan.—H. Yabe gives a summary of the Jurassic formations of Japan, which includes the Torinosu and Tetori series regarded by him as approximately equivalent. From the Torinosu limestone, included in the former, and which is fossiliferous, he lists calcareous algae, reef corals, and stromatoporoids, and more rarely ammonites (*Aulacosphinctes*, *Virgatosphinctes*, and others).

The Tetori series includes shales, sandstones, and conglomerates, of both fresh- and brackish-water origin, with *Perisphinctes*, *Seymourites*, and plant remains (*Cladophlebis*, *Nilsonia*, *Dictyozamites*, *Ginkgoites*, and others).

As most of the cephalopod genera and many of the plants are known from the

Knoxville series, and many of the plants are recorded from the "Jurassic Flora of Oregon" by Knowlton (1910), the correlation of a part of the Torinosu series with the Knoxville has support in both the invertebrate faunas and in the fossil floras.

More exact correlation of these Torinosu beds with the Knoxville series cannot be made at present, although many Japanese geologists (Shimizu, 1928); Kobayashi, 1935) have regarded the Torinosu limestone in the upper part of the series as being of Tithonian age. However, the Torinosu series has been extended downward to include older parts of the Jurassic system (Dögger) in Japan. Some beds contain radiolarian chert, the precise chronological position of which seems not to have been finally determined.

India.—In southern India an important development of Upper Jurassic marine beds is known in Cutch (Kachh), partly represented in the Zamia and Umia groups. Spath (1933) has revised this succession and (p. 864–865) has given an extensive correlation table in which these formations appear along with those of England and boreal Russia. The Portlandian and Tithonian portions of the succession are represented in the above-named groups, which are overlain by Neocomian beds. Beneath the Zamia group are the Katrol beds of Neokimeridgian age. The Zamia group includes beds correlative with the lower Volgian of Russia, with *Virgatites virgatus* and *Provirgatites scithicus*. No sharp line of separation between Portlandian and Tithonian is shown, but the Umia group is said to include *Micracanthoceras* and a perisphinctid fauna that Spath regards as "referable to lower Tithonian, or the highest Portlandian". The *Micracanthoceras* and perisphinctid fauna may be correlative with the upper zone with *Kossmatia* in the Knoxville series of California, whereas in north-central Mexico Burckhardt (1930) and Imlay (1939) show the genera *Micracanthoceras*, *Kossmatia*, and *Durangites* more abundant in Portlandian horizons than in any younger beds. In California the two last-named genera occur with species of *Aucella* that Pavlow regards as low in the Portlandian sequence.

Spath shows no regional time hiatus between Kimeridgian and Portlandian, although in northwestern Kachh the latter is said to "follow immediately on the Argovian". This overlap of Portlandian strata directly upon pre-Kimeridgian beds should be taken as showing at least a local hiatus, and, although its extent is not shown, its tectonic significance should not be overlooked, since it occupies a position in the Upper Jurassic column of that region similar to, although broader than, that between the Mariposa-Mount Jura succession and the Knoxville series. Should northwestern Kachh be shown to be the shoreward facies of the Upper Jurassic succession, this hiatus might be interpreted in terms of a diastrophic uplift, as has been seen in the California succession, following Mariposa-Mount Jura time.

Absence of ore deposits.—It has already been stated that no ore deposits of importance have been found in strata of Knoxville age. In the Coast Ranges the known ore deposits (manganese, chromium, copper, lead, gold, quicksilver, and other metals) contiguous to Knoxville strata occur primarily only in older rocks, as is the case in Del Norte, Siskiyou, Trinity, and Humboldt counties, California, and in southern Oregon. Rarely, if ever, have proved Knoxville beds been found to contain ores, except secondary deposits of quicksilver ore. Gas and petroleum have been found

in Knoxville strata, and in rare cases in quicksilver ores, although in no case in which their source cannot be traced to Knoxville beds primarily; secondary deposits of petroleum and gas are known in contiguous older rocks, although such cases are rare and unimportant. The stratigraphic relation of the Knoxville to these ore-bearing rocks in the districts south and southeast of Clear Lake is the same as that to all other terrains of the Klamath complex—namely, that of unconformity, for the most part readily recognized. However, along the line of contact north of the Wilbur Springs area, no ores are known contiguous to Knoxville beds for a distance of more than 50 miles, although these beds rest directly upon or against older rocks that elsewhere contain ores. In general throughout the Klamath Mountains, the ore-bearing rocks are far removed from Knoxville areas, including the rocks carrying the ores of quicksilver, as at Cinnabar Springs, Siskiyou County, and at many other places. This is true throughout northern California and in southern Oregon, as along the Klamath and the Rogue River valleys. In most cases the ores are known to occur in Paleozoic or older rocks, and even in more ancient schists, as in the Trinity Alps, the Salmon River, and Siskiyou Mountains. In many cases these ores are found adjacent to or within peridotites, as if they originated in them. Diller and others who have had knowledge of the subject believed that the Knoxville, including its oldest beds, is distinctly younger than the *Aucella*-bearing slates of the Mariposa region, usually regarded as of Kimeridgian age. After long acquaintance with these formations, in a review of the subject, Diller (1908a, p. 399) summarizes his conclusions as follows:

> "In California the Mariposa and Knoxville are not found together. They outcrop on opposite sides of the Sacramento Valley. The Mariposa is involved in the intense folding of the Sierra Nevada, is extensively associated with volcanic rocks, and has been considerably metamorphosed, and contains important ore bodies which have been successfully mined. The Knoxville lies chiefly against the eastern slope of the Coast Range and is not closely folded, altered, or associated with large masses of volcanics, as is the Mariposa. It rests unconformably on the strata which appear to have been folded with the Mariposa, and for this reason it is believed that if the Knoxville and the Mariposa were found together in California they would be unconformable".

These views are supported and reinforced by those of other writers and accordingly appear to be above doubt or question. The facts contained in the foregoing discussion of the Knoxville series in no way conflict with the views of Diller, but on the contrary may be regarded as an added support, if in fact any were needed.

MOUNT JURA SUCCESSION

The Jurassic formations in the region of Taylorville, Plumas County, including those about Mount Jura, 50 miles east of the type area of the Knoxville series, are in part fossil bearing and have been more systematically explored and described than have other Jurassic groups in the Sierra Nevada, and since a portion of this succession has been referred to a Tithonian or Portlandian stage it seems probably to include the latest body of Jurassic deposits known in the area of the Sierra Nevada.

These Mount Jura deposits were first described by Diller (1892) as constituting a complicated assemblage of eruptive rocks and marine sediments, much folded, overturned, faulted, and overthrust. Rightly or wrongly, later investigators have re-

viewed and have sought to rearrange the order of these formations, and in effect would discredit the work and views of Diller in this region as being of little value. Crickmay (1935) has described the succession of strata found here as being an "imbricated structure" that has "long baffled solution", but he has given its aggregate thickness as more than 9,500 feet. Of this aggregate 62 per cent is said to be of eruptive rocks, although they are interstratified with fossil-bearing marine strata, which are shown by their invertebrate faunas to belong to later Jurassic time. Much of the succession is said to be not younger than Kimeridgian, in the view of more conservative writers. The time relation of the Mount Jura succession to the Knoxville series should, therefore, be of much interest, since the time interval between them covers a hiatus in the sedimentary record of considerable importance, and accordingly of much interest.

Diller (1903) expressed the belief that the Mount Jura deposits had occupied the southwest limb of a geosyncline, which had been faulted and in part overturned, as a result of a "great thrust" that had operated upon this region from the southwest. These structural conditions and their historical aspects will be referred to later, but their significance should be interpreted in terms of major historical events, as Diller himself (1903) endeavored to indicate and as will be shown more fully later.

Following the age determinations of Hyatt, Diller regarded the Foreman formation as a late part of the succession, not earlier than late Jurassic, although he did not indicate its precise stage. Crickmay (1935), in reviewing the number and order of the several units assigned the Foreman formation to a Reineckeian stage, which in his view was followed by the Trial tuff and the Combe sandstone. The latter he assigned to a Tithonian epoch, and accordingly it should be correlated with the Newville group or with some part of it, in the upper part of the Knoxville series. It is to such assignment of the Combe, or of any Mount Jura formation, that the present writer seriously objects, and to which he wishes to call the attention of students of the Mesozoic. Without questioning at this time the competency of the evidence upon which these assignments were based, it may be pointed out that no part of the Mount Jura section can be said to resemble any group of the Knoxville series, in either lithologic character, structural features, or in faunistic aspects. In all these features there is more of contrast than of resemblance. The volcanism, the penetration of the whole by later intrusives, the compression, and especially the metamorphism of the strata have no counterparts in the Knoxville, except very locally. The "great thrust" from the southwest, which folded and faulted the Mount Jura section, cannot be doubted, but it is in no manner duplicated in the Knoxville series, although the areas of the latter are not far away and geographically are well situated to have first felt the thrust, if the two series had been synchronous in any part. This "great thrust" should have affected the Knoxville series, had it then existed, but in reality this thrust had no effect upon it, although it probably was felt in the locus of the Knoxville and throughout the Great Valley. The thrust could have been involved in the development of the Great Valley itself, as a phenomenon of the Nevadan orogeny, antedating the Knoxville sedimentation.

If any part of the Knoxville series had been laid down during an epoch of volcanic activity, such as that seen in the Mount Jura succession, its sediments should contain

some evidence of the fact, either as stream- or as wind-borne detritus (tuffs or ash). No such evidence is known, although all parts of its section have been searched.

In the invertebrate faunas in the two series there is no specific resemblance; their contrasts, as already noted, are striking. If these deposits were synchronous, their outlets to the sea would have been the same and their invertebrate faunas should have mingled and could hardly have remained wholly distinct. Of the three faunistic elements prominent in the Knoxville—namely, ammonoids, belemnoids, and Aucellae—only the first is found in the Mount Jura formations which were said to be of Portlandian or Tithonian age. Crickmay has attached little importance to the Nevadan orogeny, placing it in late Tithonian time (1932, p. 67), not in an earlier stage, as others have done.

From the foregoing statements it is clear that the chronological relationship between the Mount Jura and the Knoxville series were not close, not closer in fact than the epochs separated by the Nevadan orogeny, or its epoch. The same view applies to the relationship of the Mariposa sequence to that of the Knoxville series.

It can logically be held that the "great thrust" that folded and faulted the Mount Jura section acted at the same time, and in a similar manner upon the Mariposa sequence, but since it did not affect the Knoxville series we may infer that the thrust had preceded its epoch.

The eastern border of the Sacramento embayment of the Great Valley trough is singularly barren of any sediment, land-laid or marine, that is referable either to late Jurassic or to post Nevadan time. Near Greenwood, Eldorado County, is the type locality of *Belemnites pacificus* Gabb. Since this species resembles, or appears to represent, the genus *Cylindroteuthis* Bayle and Zeiller, a genus found abundantly in the Newville group (Tithonian part) of the Knoxville series, it might be thought to indicate this horizon on the east border of the Sacramento embayment. As shown by Stolley (1920), the genus ranges from the Dögger upward to the Malm in Europe and other regions, but he gives no warrant for its assignment to either Tithonian or Portlandian horizons exclusively.

The locality near Oroville, Butte County, Oregon, referred to as the "Monte de Oro horizon", was recently visited (1939) by the writer, but as Diller has already shown (1908a) this locality and its sedimentary formations are correlative with some part of the Mariposa sequence and may well be so accepted since it contains no evidence of being younger. It also contains mineral deposits of a character not known in the Knoxville series at any place, much less in a Tithonian or Newville horizon.

MARIPOSA SLATES

It is unnecessary to review here the sequence or composition of the Upper Jurassic in the Gold Belt of the Sierra Nevada, now generally known as the Mariposa beds or the Mariposa slates. Their relation to the Knoxville series is known chiefly from paleontological data. The faunas of the Mariposa sequence, first indicated by Meek (1865) as of Jurassic age, were more fully discussed by J. Perrin Smith and by Hyatt (1894). As partly described by the latter (but not figured), the fauna of its upper

portion included three or more diagnostic types of ammonites and four or five species of *Aucella*, with a few other forms whose types were uncertain. More recently these have been reviewed in part by Reeside (1919), and later by Crickmay (1935).

Of the several species known from the Mariposa slates none have been found in any part of the Knoxville series, but on the contrary most authoritative writers (Smith, 1895; Hyatt, 1894; Reeside, 1919; Crickmay, 1935) agree in referring them to a early Kimeridgian (Sequanian) stage. With the Mariposa slates of the Gold Belt may also be included the sequence of Upper Jurassic deposits found about Taylorville, Plumas County, and that found farther north on Pitt River, the latter reviewed by Hinds (1933).

Other areas in which Upper Jurassic marine fossil-bearing beds occur are known on the lower west slope of the Sierra Nevada, some of which have been referred to Portlandian or Tithonian stages, and accordingly might be correlated as a whole or in part with the Knoxville series on the west side of the Sacramento Valley. Pavlow (1907) assigned some of the Aucellae mentioned in foregoing lists to a "Lower Portlandian" age, but in this he has not been followed by later writers. Most American authors before and after Pavlow have regarded these beds found on the east border of the Valley as being of Kimeridgian age, and this view is supported by much collateral evidence.

Crickmay (1932) has referred *Aucella arcuata* (Hyatt) to a Tithonian horizon, but, inadvertently or otherwise, he remarks (p. 53) that: "It is obviously a near affine of *Aucella pallasi* Keyserling, as figured and described by Lahusen from the zone of *Cardioceras alternans* (Von Buch) of Russia"

The zone of this ammonite had already been shown by Smith (1894, p. 254) to range from Upper Oxfordian to Kimeridgian, and the zone of *Aucella pallasi* Keyserling has not been shown to be referable to a Tithonian stage. Pavlow discredits the name or places it in the synonomy of *Aucella mosquensis* (Von Buch), which ranges downward to Kimeridgian strata. Neither *Aucella mosquensis* (Von Buch) nor *A. pallasi* Keyserling has been reported from the locality of *Aucella arcuata* (Hyatt). Briefly, it may be stated that no evidence has yet been found that strata equivalent to any part of the Knoxville series has been found on the east border of the Great Valley of California. This fact appears to the writer to be of great significance as bearing upon the origin and history of the Knoxville series in the Mesozoic of California.

FRANCISCAN GROUP

As originally described by Lawson (1895) and later employed by him (1914), this group of formations contains characteristic types of sandstones, cherts, shales, and eruptive rocks of various classes such as are widely known in the Klamath complex in California and in southern Oregon, and in districts in which no Knoxville beds appear.

The clastic rocks of this group cover large areas in the Klamath Mountains west of the Great Valley but rarely if ever occur within it in visible outcrops. From their character, their volume, and their distribution these Franciscan rocks appear to have

accumulated during a period long prior to the epoch-making time of the Nevadan orogeny as described by Lawson (1893), Blackwelder (1914), and Hinds (1933), which was subsequent to the Mariposa sedimentation in the areas of the Sierra Nevada.

The formations of the Franciscan group were summarized by Lawson (1914) in the order of their occurrence as follows:

(5) Bonito sandstone.
(4) Ingleside chert (radiolarian chert).
(3) Marin sandstone.
(2) Sausalito chert (radiolarian chert).
(1) Cahil sandstone (including Calera limestone member and some volcanic rocks).

Each of these groups was discussed by Lawson (1895) and later by Davis (1918) and by other writers and is generally recognized by most geologists. According to Lawson the clastic rocks of this group involve various types of volcanics, and these are penetrated by types of intrusives ranging from peridotites, diabases, basalts, and others to less basic types, with or without contact minerals.

None of the characteristic components of the Franciscan group as described by Lawson (or by Davis) are recognizable in the Knoxville series as it occurs in its type areas north of the Wilbur Springs area, or in fact anywhere in its belt. The characteristic features of the Knoxville series are distinctly at variance with those of the Franciscan group. There is no important feature, lithologic or faunal, common to these contrasting groups, or series. Throughout their belts which are traceable for long distances there are more features of contrast than of resemblance; there is little in common.

It is not the intent of the writer to discuss here extensively the question of the relation of the Franciscan group to the Mariposa beds, although both appear to be definitely older than the Knoxville series, as will be shown later. Taliaferro (1943; p. 188) has regarded the Franciscan group as younger than the Mariposa beds, in which view he appears to be alone. Most authoritative writers have taken an opposite view as to their time relations.

PERIDOTITES

Comments upon the peridotites in the Coast Ranges of California and Oregon seem to be unavoidable here, chiefly on account of their relationship to the Knoxville series along many miles of contact. In their nature and history these rocks differ much from other intrusive types, especially in their lack of competency, or resistance to stress, or pressure, and their susceptibility to movements and displacements arising from any cause. Evidences of secondary movements are everywhere apparent. It cannot be assumed that a single intrusive impulse only has been involved in their record in the Coast Ranges, or in any area, since secondary disturbances are to be seen in all their areas.

Turner, who had studied these rocks in the Sierra Nevada and in the Coast Ranges extensively, had felt convinced (1895) that their first intrusion in the Sierra Nevada had antedated that of the granodiorite; and that in the Coast Ranges it had been coincident with the Nevadan orogeny. To later dates, then, must be referred the

intrusions of various sorts of dikes that cut the peridotites (or serpentine) and adjacent formations. Some of these dikes are said to have penetrated Knoxville strata as well as the serpentine with which they are associated. Such occurrences if they exist must be referred to as secondary, or of post Knoxville date. No such dikes have been seen by the writer, though numerous dikes have been seen cutting older rocks, including serpentine, in many cases far removed from Knoxville areas.

However, we may believe that the Nevadan orogeny and the development of the Great Valley trough had antedated the Knoxville series, and that the latter had been laid down upon a floor which included peridotites in the Coast Ranges, as well as in the Sierra Nevada, and had antedated the intrusion of granodiorite.

In the usual and normal contacts between peridotites and Knoxville beds there is little evidence of metamorphism, except local effects that rarely extended beyond a few yards, or a few feet. In nearly all cases in which metamorphic action is found it is more logically and better explained in other ways than that involving the primary intrusion of peridotite. The claim that primary intrusions of peridotite have cut any Knoxville strata, even the latest group, should be accompanied by satisfactory evidence, and none such has been seen by the writer.

Good illustrations of the contact and time relations of Knoxville beds and peridotite are to be found in many places in the districts south and southeast of Lower Lake (Pope Valley, Putah Creek, Sulphur Creek, Capell Creek, Childs Valley, and other places). Here, as in many other places, pre-Knoxville rocks carry notable deposits of ore (pyritic gold ores, copper, quicksilver, manganese, and other metals) and include crystalline limestone, dikes, and various contact minerals, though regional metamorphism has not been claimed, such as occurs in the Sierra Nevada.

Lawson (1895) and Palache discussed the occurrence, origin, petrology, and field relations of serpentine on the San Francisco peninsula, and by inference those throughout the Coast Ranges of California. Its progenitor peridotite or pyroxenite was thought to have entered the Coast Range geologic record during the Franciscan epoch, since in some areas these rocks dominate this group. However, since no adequate treatment of the Knoxville series and of its place in the Mesozoic column had then been given, their account of the Franciscan group (including serpentine) and its field relation to the Knoxville could not have been stated. In the type areas of the latter, north of Wilbur Springs, where the series is most complete, no recognizable Franciscan rocks are known, although igneous rocks (serpentine and metadiorite) outcrop in areas immediately south of Toms Creek, where the lowest beds of the Elder Creek group rest directly upon them. It may be added here that the above-mentioned discussion of serpentine was probably not intended to include its physical character, history, and behavior through all periods subsequent to its invasion epoch, and much was left to be considered later regarding these aspects of its occurrence. As now known to geologists and to structural engineers, this rock is by its nature and behavior one of the most unstable of all terrains, having little competency or resistance to stresses, and under them is subject to swellings, distortions, readjustments, internal movements, and other disturbances, such as to render it objectionable to informed engineers for heavy structures, dam sites, bridges, or fortifications where great stresses are expected. How then should it be regarded

by geologists who are concerned with earth disturbances in which vastly greater stresses arise in the course of earth history, and during the operation of "great thrusts" such as all informed students are taught to expect? Its field and structural relations to other and more stable terrains with which it is in contact should be considered in the light of its acknowledged character and its habits, rather than that of its present position, field relations, and contacts.

In tracing and otherwise dealing with contact relations between the Knoxville beds and the terrains of the Klamath complex, many areas of serpentine are encountered, for which the views of Lawson and Palache appear to be adequate—namely, that peridotites (and serpentine) constitute a part of the Franciscan group—and it may be added that both probably antedate the Nevadan orogeny and accordingly form a portion of the Klamath complex, of which they are important members, notwithstanding its confusing vagaries and elusive behavior, and frequently misleading appearances. The serpentine areas adjacent to the Knoxville belt form only a negligible part of its areas known in the Klamath Mountains, where this rock has no possible relation with Knoxville areas. It is less obvious that it has no relations with Franciscan rocks. In truth it is involved with them in many areas of the Klamath complex. Its habitual association is with the terrains of this complex over large areas of the Klamath Mountains.

SUMMARY AND CONCLUSION

Following historically upon the epoch of the Nevadan orogeny, by which the longitudinal trough of the Great Valley of California had been initiated, erosion and denudation set in on the slopes and in the valleys of Klamathonia, the great West American foreland of the time lying immediately to the west. This foreland had also been somewhat elevated by the same great orogenic impulses that had initiated and developed the trough.

The products of erosion and denudation were immediately picked up by its converging streams and were carried by its rivers into the trough of the Great Valley, especially into its northern embayment, into which the sea had entered from the south. Here were laid down the earliest marine sediments of the trough, the sediments of a new regime of later Mesozoic time on the West American Coast.

This departure from the older (Modin-Bagley-Potem) dynasty had been initiated in an early Portlandian epoch, and its operation had continued in middle Portlandian time, with the detrital products of river drainage from the slopes and valleys of Klamathonia, and the building up within the northern embayment of the trough the sedimentary succession that is here described. This covers the later part of Jurassic time.

From the early stages of the new order no organic record has been preserved; there are remaining only barren marine strata that now show only the contorted product of enormous pressure under an accumulating load of detrital sediment 16,000 feet in thickness, seen chiefly as indurated shales, or as a series of alternating cherty and sandy shales, sandstones, and more recent sandy shales. These make up the major part of this entire sedimentary accumulation with which we are here concerned.

The earliest marine life of which we have record in the sedimentary succession of the period was pelecypods and belemnoids in limited varieties and in sparing numbers, insofar as they are now known to us. In the progress of later (middle Portlandian) time, the western border of the embayment was enlivened with molluscan life, limited to only a few types, chiefly of pelecypods, and a scanty fauna of ammonoids. Terrigenous deposition and an increasing molluscan fauna continued to the close of Portlandian time, but with an interval of diastrophism and of readjustment that divided the sequence of sedimentation into two distinct and disconformable groups of strata, the Elder Creek group below and the Grindstone group above, each with its own lithologic types of sediment and its own peculiar types of molluscan life. Only the earlier of these groups is known to carry cephalopods, ammonoid or belemnoid. The Grindstone group is chiefly given to coarse sandstones and pebbly conglomerates. Its fauna is almost limited to pelecypods, including the genus *Aucella*.

At the close of Portlandian time a widespread disturbance, or an interval of diastrophism, ensued, at the close of which a regional subsidence within the areas of the trough is evident and also is clearly seen in lateral and especially in longitudinal expansions of marine occupation beyond the limits of the Great Valley trough. However, Tithonian time witnessed continued detrital sedimentation from the same areas as before, but more remarkable invasions of new molluscan types into the trough not before found in it. Tribes of ammonoids, belemnoids, and of pelecypods new to the trough, and to the West Coast, were among the invertebrate immigrants of this epoch. Most of these immigrants, as well as the types that had preceded, were of Russian lineages, and probably of Russian origin, though there were others of Mexican or Andean types, and perhaps of such derivation, though this has not yet been proved to be their source. In the organic records existing in the several groups of the series its historical features are to be read most clearly, as shown in the preceding pages.

It was this series of terrigenous sediment that was first recognized by G. F. Becker and C. A. White, not in its entirety, but in its upper group only, near the old mining camp of Knoxville, and at the Reed mine, to which Becker attached the name Knoxville series, not knowing that the strata exposed in these areas represented only its latest group and little more than half its entire stratigraphic succession. The older group of the series these writers knew only vaguely, though they extended the series downward to the lowest range of the genus *Aucella* in the Coast Ranges of California (Becker, 1888).

The upper limit of the Newville group and of the Knoxville series is clearly marked by the overlapping beds of the Shasta series, which contain in their conglomerates boulders and blocks of concretionary lenses derived from the Newville group, containing fossils from the same that carry their own evidence of unconformable relations.

DESCRIPTIONS OF SPECIES

The following treatment of invertebrate species found in the Knoxville series cannot be regarded as either complete or in all cases final, but the views here offered

constitute the results of a prolonged study of the field and of its faunas by the writer. It is hoped that these results are of sufficient interest to induce later students of the subject to search the field anew for more and better materials. For the identification of some of the forms thus far found there is no adequate collection available for comparative study, and from necessity reliance has been placed upon the figures and descriptions given by recognized authorities both here and abroad, as found in the literature bearing upon the faunas of the later Jurassic in countries bordering the Pacific basin, or in Europe, or in other related regions. Much aid has been found in the suggestions of Stanton, in the works of Pavlow (1907) and of Sokolow (1908a; 1908b) bearing upon the Volga basin and of more northern regions, and in the discussions given by Spath concerning the correlative faunas of Cutch, India, especially those dating from 1930 to 1934, dealing with the later Jurassic of India.

For the determinations of Aucellas the work of Pavlow (1907) has been of great service, particularly in his interpretations of the examples obtained by him from the Knoxville of California, which he has figured. Unfortunately he had little stratigraphic information as to the occurrence of the various species included in his accounts. Some of the belemnites from the Newville group appear to be close analogues, if not actually descendants of species occurring in England or in continental Europe in beds that seem to be correlative, although no direct connections are here claimed to have existed. Concerning some of the ammonite types, Stanton (1895) had already compared certain of the berriasellids from the Newville group in northern California with some from correlative deposits in Europe and in Mexico, and the Andean countries, although probably without an exchange of materials from correlative beds. Burckhardt had recognized the close relationship of *"Hoplites" storrsi* Stanton with *Berriasella* cf. *B. calisto* (his own) from Tithonian beds occurring in north-central Mexico, and probably in Andean America. The summary account of the Upper Jurassic in Mexico given by Burckhardt (1930) has aided greatly in the correlation of the Newville group with presumable stratigraphic equivalents in north-central Mexico; the work by Imlay (1938; 1939) has also been helpful in correlations, if not in suggesting lines of communication with Europe and England by a southern route. The works of Uhlig (1903; 1910) on the Spiti shales, and of Spath (1931) on the faunas of Cutch, India, have been suggestive and of value for generic determinations and helpful in correlative attempts. The age determination and the chronological assignment of California types have been guided more by their actual occurrence in the California column as found in the field itself.

Phylum ECHINODERMATA

Few remains of echinoderms have been found in the Knoxville series in any part of California, and for this reason the following records appear to be justified. About 1939 Cordell Durrell discovered in Upper Knoxville beds almost immediately, and probably unconformably, overlying siliceous cherts of the Franciscan group remains of both *Pentacrinus* and *Ophiurites?* associated with various forms of *Aucella*. Later Durrell and the writer collected from these beds *Aucella stantoni*, *Aucella hyatti* Pavlow, and *Aucella knoxvillensis*. More recently R. L. Rist and the writer collected from associated shales, about 1,500 feet higher in the section, species of a perisphinctid type of ammonite associated with Newville species of *Aucella*. The faunal assemblage in these beds is regarded as representing a Tithonian horizon, rather high in the Knoxville series. In the lower

beds of this locality, 1 mile north of Lake Chabot, the following species of brittle star was discovered by Durrell.

Ophiurites (or ***Ophioglypha?***) sp. indet.

A complete description of the species represented by the remains thus far found cannot be given. The disc is depressed, nearly circular in outline, obscurely marked by an angular plate, and has slender, curving arms 19 mm. in length, tapering to a long narrow point. The species appears to belong to the genus *Ophioglypha* Lyman, but this cannot yet be determined. The locality is shown on the map of the San Francisco Folio (1914). These remains were found in dark sandy shale not far above the lowest exposed Knoxville beds, associated with the above-mentioned invertebrate forms, indicating a Tithonian age for the beds.

Phylum MOLLUSCOIDEA

Class BRACHIOPODA Dumeril

Family RHYNCHONELLIDAE Gray

Rhynchonella schucherti Stanton

(Plate 5, figure 11)

Rhynchonella schucherti STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 31, Pl. 1, figs. 1–4; 3.7 miles northwest of Paskenta, Tehama County, California.

Stanton's characterization of this species requires no emendment. The specimens occur in great numbers in what seems to have been a single colony, although mingled with shells of other genera and species. Stanton had collected here in a limited area no less than 100 specimens, and Rist and the writer obtained an equal number at the same place, in a space of 10 feet along the outcrop of the stratum. The limestone body in which this species predominates contains many other genera of pelecypods, including *Aucella piochii* Gabb, *Aucella terebratuloides* Lahusen, and, according to Stanton, numerous other genera. It outcrops near the base of the Newville group and, as estimated by Stanton, about 3,000 feet below the summit. The lens of limestone is so exceptional in the midst of a thick body of shale that it appears probable that the lime carbonate was largely derived from the shells of this species. The association of species collected from this lens is remarkable and seems to indicate a position near shore, though not on the strand line. No similar occurrence is known in any part of the Knoxville series.

Family TEREBRATELLIDAE King (emend. Beecher)

Genus ***Terebratella*** d'Orbigny

Terebratella aff. ***T. californica*** Stanton

Terebratella californica STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 33, Pl. 1, figs. 12, 13; near Stephensons on Cold fork of Cottonwood Creek, Tehama County (Lower Cretaceous).

A single valve of *Terebratella*, related to *T. californica* Stanton, was found by Durrell in the Newville beds a mile north of Lake Chabot, in the southern part of the Berkeley Hills. It was associated with *Aucella hyatti* Pavlow, *Aucella stantoni* Pavlow, and other species of the genus in beds near the local base of the series. Not far away, in beds about 1,500 feet higher in the section, were found *Perisphinctes* sp. and *Aucella piochii* Gabb. From the assemblage of species found with it, as well as from its stratigraphical position, the species is regarded as here representing a Tithonian horizon in the Knoxville series.

Phylum MOLLUSCA

Class PELECYPODA

Only a limited number of pelecypod species, and fewer genera, are known from the Knoxville series, and of these *Aucella* occurs in the greatest abundance and is represented in its type area by a considerable number of species. A few of these have a stratigraphic range almost throughout the series; others have a very much restricted range. Various other pelecypods have been described from the series, but their total number is less than that of *Aucella*. Pelecypods are found more abundantly in three major zones—namely, near the bottom of the series, near the top of the Grindstone group, and near the base of the Newville group.

A list of species, representing a number of genera, was given by Stanton (1895, p. 17) collected from a small limestone lens near the base of the Newville group, 3.7 miles northwest of Paskenta, but this occurrence is quite exceptional. Stanton's descriptions are not repeated here, but his illustrations of six of the forms are given in plate 5 of the present paper.

Fig. 2. *Lucina ovalis* Stanton, (1895, p. 59, pl. 12, fig. 1);
Fig. 3. *Solemya occidentalis* Stanton, (1895, p. 55, pl. 10, fig. 2);
Fig. 4. *Nucula gabbi* Stanton, (1895, p. 51, pl. 6, figs. 11, 12);
Fig. 5. *Corbula? persulcata* Stanton, (1895, p. 61, pl. 11, fig. 3);
Fig. 6, 6 a. *Cardiniopsis unioides* Stanton, (Stanton, (1895, p. 55, pl. 8, fig. 1; pl. 10, fig. 1));
Fig. 7 a, b. *Nucula storrsi* Stanton, (1895, p. 52, pl. 6, figs. 13, 14).

The Jurassic aspect of some of these species was recognized by Stanton, and an analytical study of the list given in another place shows them to belong to a low horizon in the Newville group. To the list of pelecypod species found in the Knoxville series we may add the following four species from this group.

Family PERNIDAE Zittel

Genus *Inoceramus* Sowerby

Inoceramus scotti Anderson, n. sp.

(Plate 15, figure 1)

This species is represented by a single example, of which the left valve is fairly well preserved; the other is less so. Its most striking features are its large size, rather robust form, and the general curvature of the shell as a whole. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (incomplete), 9 inches (228 mm.); thickness (both valves), 2 inches (51 mm.). The shell is inequivalve, obliquely ovate, or subovate; surface marked by broad concentric undulations that become more irregularly spaced with growth; beaks terminal and apparently narrowly rounded; hinge seemingly short and oblique to the longer axis of the shell; valves not thick, brittle and easily fragmented, thinner at the posterior end of the shell. This specimen, the holotype, was found (Loc. 28,609, Calif. Acad. Sci.) by Dr. Gayle Scott, 3.5 miles north of Winslow bridge, on the Alder Springs road, Glenn County. It was found associated with *Lytoceras* sp., *Perisphinctes* (*Proniceras?*), *Aucella fischeri* d'Orbigny, and other invertebrate species, in nearly the zone of Loc. 28,037 (Calif. Acad. Sci.). The species may belong to the lineage of *Inoceramus ovatoides* Anderson from the lower beds of the Horsetown group (Cretaceous), which it resembles in outline, though this cannot be proved. It is named in appreciation of the interest taken in the Mesozoic formations of the West Coast by the discoverer and of his work in Texas and in other regions.

Inoceramus stantoni Anderson, n. sp.

(Plate 15, figure 2)

This species is of moderate size, ovate in outline, beaks terminal, hinge short, exterior angle obtuse- the borders of the shell meeting at an angle of about 100°; surface marked only by concentric undula,

tions and faint radial lines seen on the cast of the shell. The species is quite unlike *Inoceramus ovatus* Stanton, except in size and surface markings, which are somewhat less oblique, with a wider angle at the beak and with more flatly convex valves. Its stratigraphic position is probably near that of the latter, but it is known only from the locality of the holotype. The holotype (Calif. Acad. Sci. type Coll.) measures: length, 85 mm.; width, 50 mm.; valves nearly equally convex, rather flat, the combined thickness being about 15 mm. The holotype was found in the Newville group on the south bank of Grindstone Creek, about 1,200 feet west of the iron bridge on the Winslow-Paskenta road, where it was associated with *Aulacosphinctes taffi*, nov., *Protacanthodiscus* sp., and *Aucella fischeri* d'Orbigny var. It is regarded as representing a horizon very near that of Loc. 28,037 (Calif. Acad. Sci.) not far to the north.

Inoceramus ovatus Stanton

Inoceramus ovatus STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 47, Pl. IV, fig. 15; South fork of Elder Creek, Tehama County.

Stanton's description of this species is sufficiently clear and needs no special comment and is included here only to call attention to its stratigraphic position in the Knoxville series. The holotype was found on the South fork of Elder Creek, about "2,000 feet below the top of the Knoxville beds," where a single specimen was found associated with *Aucella piochii* var. *ovata* and *Belemnites tehamaensis* Stanton.

From Stanton's description of the locality, and from the associated species given by him, there can be no doubt as to the position of the holotype. It is at the horizon of Loc. 28,037 (Calif. Acad. Sci.) and therefore in the Newville group of the series. This locality is believed to be about 1,800 feet below the top of the group. It therefore appears that few if any beds of Paskenta age are included in this section of the Knoxville as given by Stanton.

Family PECTINIDAE Lamarck

Genus *Pecten* Muller

Subgenus *Syncyclonema* Meek

Pecten (*Syncyclonema*) cf. *P. concentrica* Kock

(Plate 15, figure 4)

A single well-preserved specimen of a left valve of this genus was found at Loc. 28,609 (Calif. Acad. Sci.) on the Alder Springs road, 3.5 miles north of the Winslow bridge, western Glenn County. It is nearly circular in outline; surface smooth, showing only concentric lines of growth; hinge nearly straight, the anterior ear faintly plicated; the angle at the beak is about 80°. In size and other characters the shell resembles the species figured by Weaver (1931, p. 273, pl. 28, fig. 170) as *Pecten* (*Entolium*) *disciformis* Schuebler and assigned to the Liassic.

The specimen here figured has the following dimensions: height, 14 mm.; width, 12 mm.; thickness, 3 mm. This example was found associated with *Inoceramus scotti* nov., *Aucella hyatti* Pavlow, and a perisphinctid species, in the upper part of the Newville group. The horizon of the species is that of the preceding species.

Subgenus *Chlamys* Bolton

Pecten (*Chlamys*) *risti* Anderson, n. sp.

(Plate 4, figure 7)

This species is known only from the holotype, which is a rock mold of a single left valve. The shell is subcircular in outline, left valve moderately convex, radially ornamented with fine, regular,

and beaded threads extending from apex to base, the beads only faintly showing on the mold; surface marked by rounded concentric undulations crossing the radial ribs; only the anterior ear is known, which is also radially striated; angle at the apex of the shell about 90°. The holotype (Univ. Calif. type Coll.) measures as follows: total height, 15 mm.; width, 13 mm.; convexity of left valve, 2 mm. The holotype was found by Robert L. Rist at Loc. A-2921, 5 miles northwest of Paskenta, in the upper part of the Elder Creek group of the Knoxville, associated with *Kossmatia tehamaensis*, nov., and a species of belemnite, about 4,500 feet above the base of the series and perhaps about 7,500 feet below its summit. The species is named for its discoverer, to whom the writer owes much for his enthusiastic co-operation in the difficult work of exploring the type area of the Knoxville series. The species is regarded as marking the upper-middle part of the series as a whole.

Family Pteriidae Meek

Genus *Pteria* Scopoli

Subgenus *Oxytoma* Meek

Pteria (*Oxytoma*) *californica* Anderson, n. sp.

(Plate 15, figures 5, 6)

The shell of this species is of moderate size, subtriangular in outline; valves inequal; left valve highly arched, costate. with 10 rounded radial ribs diverging evenly from the apex; surface also marked by lines of growth seen both on the ribs and in the interspaces; hinge moderately short, a little produced behind; shell somewhat oblique. The species is closely related to *Oxytoma mucronata* Meek, as figured by Whiteaves from the east side of Aliford Bay, Moresby Island, British Columbia (Yakoun formation), but it has fewer ribs and is less oblique.

The holotype (Calif. Acad. Sci. type Coll.) is a left valve; height, 17 mm.; width, 17 mm. The paratype (Calif. Acad. Sci. type Coll.) is a right valve: height, 17 mm.; width, 17 mm. These examples, with a smaller left valve, were collected by J. A. Taff and C. M. Cross at Loc. 28,660 (Calif. Acad. Sci.), 0.4 mile west of Paskenta, Tehama County, apparently in the Newville group, associated with *Aucella trigonoides* Pavlow.

The same species has been found in the same horizon on Redbank Creek, where it was found associated with a species of gastropod.

Another species of the genus was found by Bennison on Quinto Creek, Stanislaus County, in the lower beds of the Newville group, though it is not here described.

Family Myalinidae Frech

Genus *Aucella* Keyserling, 1843

The Knoxville series is especially rich in types and numbers of *Aucella*[2], which as a genus is distributed throughout its column from its lowest to its highest beds. A few of these range throughout the series; others have a more restricted vertical range. Most of the species here recognized have already been identified or described by Pavlow (1907), and a few new species have been added.

[2] An attempt has been made by some writers to discredit the name *Aucella* and to replace it with "*Buchia*", a name proposed by Rouillier in 1845, but not accepted. Whatever claim may now be made for the validity of the latter, the fact remains that most specialists in this branch of paleontology, since the time of Keyserling, have accepted the name *Aucella* proposed by him, which, after more than 80 years of recognition and use, has become so well established in the literature that no rule should now be invoked to replace it. It would appear that the matter had been sufficiently settled by Pompeckj (1901), but for those who may still be unconvinced it may be recalled that Rouillier gave neither figure nor description, nor any characterization of the fossil upon which he proposed to found the name "*Buchia*", but merely submitted to his society a specimen which he supposed represented "*Avicula*" *mosquensis* von Buch. Whether this shell was properly identified by him few students of the subject have now any means of knowing, and fewer still have any interest in the matter. For this reason the name "*Buchia*", as remarked by Pompeckj, "did not meet with approval, as opposed to the name *Aucella*, and the better characterization provided by Graf Keyserling for the new genus".

Pavlow's excellent illustrations and his zonal chart showing their columnar distribution have been helpful in identification. Their abundance in the Knoxville series in the Great Valley, and their excellent preservation, can hardly be surpassed. In the following descriptions only those forms that are diagnostic of one or another of the stratigraphic groups have been included, although others could have been distinguished. The aucellan stocks in the Knoxville series do not appear to represent any found in the Mariposa succession, but on the contrary they belong to distinct lineages that have arrived upon these shores from other regions following some important event in the physical history of the Pacific basin. Not many of those found in the Knoxville series had survived into the succeeding Shastan epoch, in which a new lineage began. In a considerable measure those found in the Portlandian groups do not appear to have continued into the Tithonian Newville group. These changes, easily recognized in the aucellan succession in the West Coast Mesozoic, can hardly be attributed to local disturbances or to changing environmental conditions, but they appear to have followed far-extended causes that involved other types of Mollusca as well, although notably the genus *Aucella*, as in the Upper Jurassic of Russia, well shown by Pavlow (1907).

In a manner somewhat analogous to the succession of aucellan types occurring in the several epochs of late Mesozoic time on the West Coast, we may recognize a sequence of such types in the successive stratigraphic groups in the Knoxville series itself in the Great Valley of California. The species most representative of the Elder Creek group do not continue into later groups, but instead new types appear that have not been recognized in earlier strata. For example, the Elder Creek group abounds in species of the lineage of *Aucella bononiensis* Pavlow, *A. elderensis*, nov., *A. mosquensis* (Buch), *A. sollasi* Pavlow, *A. gracilis* Pavlow, *A. stantoni* Pavlow, and *A. gabbi* Pavlow, few of which have been found in either of the following groups. On the other hand, in the Newville group, new types appear, such as *Aucella knoxvillensis* nov., *Aucella fischeri* d'Orbigny, *A. subinflata* Pavlow, *A. trigonoides* Pavlow, *A. subokensis* Pavlow, *A.* n. sp. B, *A. tenuicollis* Pavlow, and others not previously known in the series. A parallel succession of types is recognizable in other classes of Mollusca, each stratigraphic group containing one or more not found in the others.

Aucella piochii Gabb

(Plate 3, figures 1–5)

Inoceramus piochii GABB, Paleont. Calif., vol. 1, 1864, p. 187, Pl. 25, fig. 173 (not 174); north side of Mount Diablo, Contra Costa County.
Aucella piochii GABB, Paleont. Calif., vol. 2, 1869, p. 194 (in part, not Pl. 32).—WHITE, U. S. Geol. Survey, Mon. 13, 1888, in part.—PAVLOW, 1907, p. 54, in part only.
Buchia piochii STEWART, Acad. Nat. Sci. Philadelphia, Spec. Pub. No. 3, 1930, p. 108–111 (in part, not Pl. 2, fig. 3).—CRICKMAY, Am. Mid. Nat., vol. 13, 1932, p. 5.

The species was originally described from specimens collected on the north side of Mount Diablo, probably on Bagley (Donner) Creek, 2 miles southeast of Clayton, where the species has since been found. A careful search of this and neighboring localities has resulted in finding six distinct species of the genus here, including *Aucella piochii* Gabb, which is here not abundant. The typical form (Gabb, 1864, Pl. 25, fig. 173) is comparatively rare, in this and in other areas, although other species closely resembling it have often been mistaken for it. The list of species from its type locality near Mount Diablo (Loc. 27,846, Calif. Acad Sci.) includes the following: *Aucella piochii* Gabb, *A. stantoni* Pavlow, *A. russiensis* Pavlow, *A. hyatti* Pavlow, *A.* cf. *gracilis* Pavlow, *A. attenuata* n. sp.

The holotype of *Aucella piochii* Gabb has not been certainly recognized, and it may have been lost, but topotypes have been obtained from the locality described above, and two of them have been figured and correctly represent the species.

Topotypes were found on the west branch of Bagley Creek, 2 miles from Clayton. The largest, which might be regarded as a neotype, has the following dimensions: left valve, greatest length, 35 mm.; greatest width, 10 mm.; thickness of both valves (est.), 14 mm.; thickness of left valve, 7.5 mm.

The beak is long and narrow, tapering to a point, and strongly incurved. In the specimen figured (Pl. 3, figs. 2, 3) the beak is foreshortened by down-bending by rock pressure, as is plainly seen in the figure and in the specimen. The confusing record of the name *Aucella piochii* led Pavlow (1907) to seek its abandonment; he proposed the name *Aucella gabbi* instead, but, in addition to

the inadequacy of his reason for so doing, the specimen figured by him under this name and said to occur in Russia and California appears to be distinct from that described by Gabb and is so treated in this paper. Other writers have believed that *A. piochii* Gabb occurs in both the Knoxville and Shasta series, but, as Stanton has shown, it has a considerable vertical range, occurring in each of the three stratigraphic groups of the series. It has not been recognized in the Shasta series by the writer, although another smaller form has been found, having a quite distinct form and outline.

Gabb has mentioned "*Belemnites impressus*" and "*Ammonites remondi*" among the species said to have been found at the type locality of *A. piochii*, but this seems to have been an error. *Acroteuthis impressa* (Gabb) has often been found in the Paskenta group of the Shasta series, but it has not been seen in any earlier horizon by the writer. The species of ammonite referred to by Gabb is not known; *Aulacosphinctes diabloensis*, nov. appears to have been found at this locality, and this may have been the form referred to "*Ammonites remondi*" by Gabb.[3]

Aucella gabbi Pavlow

(Plate 3, figures 6, 7)

Aucella piochii Gabb (STANTON, in part), U. S. Geol. Survey, Bull. 133, 1895, p. 42, 43, Pl. 4, figs. 2, 3 only (not fig. 5).
Aucella gabbi PAVLOW (in part), Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 54, Pl. 4, figs. a–c.

It appears that both Stanton and Pavlow had misunderstood the form originally described and figured by Gabb under the name *Aucella piochii* Gabb. Some of the figures given by Stanton (1895, Pl. 4, figs. 2, 3), here reproduced, were thought by Pavlow (1907) to represent a species occurring in the Upper Jurassic of Russia, to which he gave the name *Aucella gabbi*. This species appears to occur in California, but in a low horizon in the Elder Creek group. It differs from *Aucella piochii* Gabb in a number of details. The body of the shell is broader relative to its height, somewhat quadrate in outline, more broadly rounded at the posterior end; the beak is shorter, less slender; and the left valve is not so thick. This species has not been found abundant at any place in the Knoxville series, and for this reason it is thought to be rare in the type area of the series, although it may be more abundant in Russia.

The examples figured by Stanton were obtained by him on the South fork of Elder Creek, or farther north in Tehama County, where they have been found by the writer. The smaller example (Stanton, Pl. 4, fig. 5) appears to be more nearly related to *Aucella elderensis*, nov. than to any other known species. Many examples of the latter have been obtained (Loc. 29,694, Calif. Acad. Sci.) in the Elder Creek group of the Knoxville series, and not unlikely at the locality mentioned by Stanton.

Aucella sollasi Pavlow

(Plate 3, figures 8–11; Plate 2, figures 9, 10)

Aucella piochii STANTON (in part), U. S. Geol. Survey, Bull. 133, 1895, Pl. 4, fig. 4 only; Knoxville beds (Elder Creek group), 2.75 miles northwest of Paskenta, Tehama County.
Aucella sollasi PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 39, Pl. 1, figs. 8a, b; Portlandian, England.

Pavlow has regarded *Aucella erringtoni* Gabb, as figured by Meek (1865, p. 479, Pl. 1, fig. 2) as probably identical with *Aucella sollasi* from the Knoxville, but the resemblance does not appear to

[3] In the collections of the Academy of Natural Sciences at Philadelphia, there is a rock specimen containing an example of *Aulacosphinctes* and imperfect examples of *Aucella*, similar to some of the forms that have been found near Mount Diablo, mentioned above. The rock specimen is labelled only with a large "D" and is among a number of *Aucella* specimens that were kindly loaned to the writer, probably found on Bagley Creek, and so indicated by the initial letter to indicate "Diablo". *Acanthoplites remondi* (Gabb) is from the Lower Albian strata outcropping on the North fork of Cottonwood Creek, Shasta County.

be striking. Only a few examples of *Aucella* have been found in the Knoxville series that show radial striae such as are seen in Meek's figure. The examples here figured are generally quite smooth; most of them were obtained on the old road grade above the camp at the Reed mine, 4.5 miles northwest of Knoxville, and consist of left and right valves not belonging to the same individuals. The species occurs also on the South fork of Elder Creek, near the Pellow's homestead, and at other places in a somewhat higher horizon. The species occurs more commonly near the base of the Elder Creek group.

Aucella aff. *A. mosquensis* (von Buch)

(Plate 4, figure 12a, b; Plate 12, figure 3)

Not *Aucella mosquensis* (Von Buch), KEYSERLING, nor LAHUSEN.
Avicula mosquensis VON BUCH, Neues Jahrb. f. Min. Geol. und Paleont. 1844, p. 537, Pl. 4, fig. 1.
Aucella mosquensis, LINDSTROM, Om Trias-och Jura forst. fran Spetsbergen, 1866, Pl. 3, fig. 3.
Aucella mosquensis (VON BUCH) PAVLOW, 1907, p. 22, Pl. 2, figs. 5 a–c; 6 a–c; 7 a, b; 8.

Only a few examples that closely resemble the figures of this species as given by Von Buch, or by Pavlow, have been seen by the writer, but they occur in the lowest exposed beds, or near basal beds of the Elder Creek group of the Knoxville in its type areas. J. P. Smith (1894, p. 257) reported finding the form figured by Lahusen north of Mount Hamilton (Alum Rock Canyon) and on Stephens' Creek, west of Mountain View, California. One of the examples here figured (Pl. 4, fig. 12) was found by J. A. Taff, 1.5 miles southwest of Chrome, Glenn County, in beds of the Grindstone group, and the other (Pl. 12, figs. 3, a, b) was found by the writer, associated with *A. bononiensis* Pavlow, in the lower part of the sequence exposed on Sulphur Creek, Colusa County, 4 miles above the mouth of the creek.

The form found here is quite inequivalve and somewhat inequilateral; the left valve is unusually convex, its beak is drawn backward and projects above that of the right valve; the point of the beak is slightly inclined forward, according to the growth of the shell; the posterior ear is well developed. The right valve is slightly convex; the convexity is more pronounced on the posterior third of the valve. According to Pavlow (1907) the species is found in the zone of *Virgatites virgatus*, and

"Upon the Volga good specimens of this species are found in the bituminous shales of Gorodistche; some less complete specimens are found in subjacent shales of the lower Portlandian, and of the Kimmeridgian. In older beds *Aucella mosquensis* is ordinarily replaced by another species very close to what is often cited in older works, under the names *Aucella mosquensis* and *Aucella pallasi*".

Aucella knoxvillensis Anderson, n. sp.

(Plate 3, figures 12–14; Plate 4, figure 6)

Aucella pallasi, WHITE (not KEYSERLING), U. S. Geol. Survey, Mon. 13, 1888, p. 232, Pl. 4, fig. 19 only, near Knoxville, Napa County.
Aucella erringtoni, PAVLOW (in part), Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 53 (including White's Pl. 4, fig. 19).

White's figure (1888, Pl. 4, fig. 19), which represents this species correctly, is quite distinct from *A. erringtoni* Gabb, from the Mariposa slate in the Sierra Nevada.

White states that the radial lines shown in his figure "have been made a little too distinct by the artist," and for most examples, illustrating only the cast, this is correct. In the types here figured from 1 mile north of Knoxville (probably the locality of White), the radial lines are rarely seen with a lens, as in White's figure, though not in all examples. The locality from which White's example seems to have come represents only the Newville group (Tithonian in age) and not the lowest portion of the series, from which it is stratigraphically far removed.

Good examples of this species are not abundant at any place, although a number of them have been collected from the locality near Knoxville; none have been found in the Elder Creek group, well exposed on the South fork of Elder Creek (as at Loc. 29,694, Calif. Acad Sci.), from which no examples showing radial striations have been obtained by the writer.

Aucella elderensis Anderson, n. sp.

(Plate 4, figures 1–4)

Aucella erringtoni, WHITE (not GABB), U. S. Geol. Survey, Mon. 13, 1888, p. 232, Pl. 4, fig. 18; near Knoxville, Napa County.

Aucella piochii, STANTON (in part) U. S. Geol. Survey, Bull. 133, 1895, p. 42, Pl. 4, fig. 5?, South fork of Elder Creek, Tehama County. (*See* Stanton, 1895, p. 44.)

Aucella erringtoni, PAVLOW (in part), Nouv. Mém. Soc. Impér., des Natur. de Moscou, T. 17, 1907, p. 63, Pl. 4 (including White's fig. 18).

Aucella elderensis, nov., may easily be confused with *A. knoxvillensis*, with which it does not occur; it is larger, more triangular in outline, and more strongly curved. The usual form has a nearly straight posterior margin, a deeply curved anterior border, and a strongly curved beak. Many of the examples show fine radial lines extending from the beak downward, more clearly seen on the right valve but difficult to reproduce photographically. They are easily seen with a lens, on the shell itself, and sometimes on the cast. The holotype (Calif. Acad. Sci. type Coll.), with many other examples, was found at Loc. 29,694 (Calif. Acad. Sci.) associated with *A. bononiensis* Pavlow, *Durangites* aff. *vulgaris* Burckhardt; and with *Kossmatia* aff. *K. kleinsorgensis*, nov. at other places. The figure given by White (1888, Pl. 4, fig. 18) from near Knoxville, and that of Stanton (1895, Pl. 4, fig. 5) appear each to represent distinct species. The present species has been found only in the lower 2,500 feet of the Elder Creek group, and more frequently near the base of the series.

Aucella gracilis Pavlow

(Plate 3, figure 22)

Aucella gracilis PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 31, Pl. 3, figs. 29, 30; Lower Portlandian, Tatarovo, near Moscou.

This species has been found on the South fork of Elder Creek near the Hull ranch, within 2,500 feet of the base of the series, associated with the preceding species and with *A. sollasi*, *A. stantoni*, and *Durangites* aff. *vulgaris* Burckhardt. In form the shell is rather narrowly oval in outline; the left valve is curved, has a prominent beak, strongly turned toward the right; the right valve is nearly straight on its dorsal border, broadly rounded below; both valves are marked with fine radial lines, more distinct on the right valve, where they are readily seen with a hand lens; they are less distinct on the left valve and do not lend themselves to photographic reproduction. According to Pavlow, the species is closely related to *A. mosquensis* (von Buch) and could be regarded as a variety, although it is more slender and graceful. It is found in the lower and middle Portlandian beds of Russia and should be expected at the same horizon in California, where it is found.

Aucella aff. *A. bononiensis* Pavlow

(Plate 4, figure 11)

Aucella bononiensis PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 56, Pl. 4, figs. 1, 1a, 2–6; lower Portlandian, near Boulogne, and from clays of the upper Spilsby, England.

This species has not before been recognized in the Knoxville of California, but many good examples have been found at various places near the base of the series. The shell is small and relatively narrow; the left valve often pear-shaped and sometimes curved; beak of left valve overhanging the shorter right valve; right valve flattened, broadly rounded in front; nearly straight behind. The species appears to be related to *A. andersoni* Pavlow, but it is smaller, has a more nearly triangular outline, and a more pointed beak. It has been found usually in the lower beds of the Knoxville series, as on Bear Creek, Colusa County, and on Toms Creek, Tehama County. On Bear Creek it occurs 0.6 mile north and 0.3 mile south of the bridge at the mouth of Sulphur Creek; near Pellow's homestead, in the NW ¼ sec. 35, T. 25 N., R. 7 W., on the South fork of Elder Creek, where it occurs

within 1,200 feet of the base of the series. It appears to occur for the most part in colonies, separated from other species, although other forms have been found near it. It, or a closely related species, has been found on Quinto Creek, Stanislaus County, where it was obtained by Bennison, associated with *Oppelia (Streblites) quintoensis*, nov., *Haploceras pachecoensis*, nov., and *Aucella krotovi* Pavlow. The species appears to belong especially to the Elder Creek group of the Knoxville series.

Aucella cf. *A. bononiensis* Pavlow

(Plate 6, figure 5)

This form greatly resembles the preceding and may be only a variety of it, but if so the strata in which it occurs are stratigraphically lower in the series than has been thought probable. The locality of its occurrence is one of especial interest, since if beds exposed here are Portlandian this is the only known locality of the same south of Wilbur Springs, Colusa County.

Aucella andersoni Pavlow

(Plate 6, figure 4)

Aucella andersoni PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 57, Pl. 4, figs. 6 a–e; 9, 10, 11 a–c; 12. Upper Jurassic, Russia, and lower part of Knoxville beds, California.

Pavlow has illustrated forms from both Russia and California under this name. The examples from California are said to have come from near Paskenta and therefore from the upper part of the Knoxville series, though this may not have been intended.

An example from the Government of Simbirsk, Russia, was thought to be Lower Cretaceous, but this view seems to require some added support. No examples of the species have been seen by the writer from near Paskenta, nor from the zone there represented, but many have been found in the lower part of the series, and especially on Quinto Creek, Stanislaus County, where they are associated with *Aucella krotovi* Pavlow, *A. stantoni* Pavlow, and with others that occur in the lower part of the series. All examples so far found by the writer are smaller than those figured by Pavlow, except that figured by Stanton (1895, Pl. 4, fig. 8), included by Pavlow in this species. All other examples are near the size here figured.

The species appears to be related to *Aucella bononiensis* Pavlow, although somewhat larger, and is a little curved in outline. It occurs at a somewhat higher horizon in the Elder Creek group, here regarded as of Portlandian age.

Aucella russiensis Pavlow

(Plate 3, figure 21)

Aucella russiensis PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 50, Pl. 3, figs. 14 a–c; 15 a, b; middle Portlandian, Russia.

This species is not abundant in the Knoxville series but has been found on the South fork of Elder Creek, 2.5 miles northwest of Cooper's place, and on Bagley Creek, north side of Mount Diablo, Contra Costa County. Some of the examples found on Elder Creek, Tehama County, are 2 inches (51 mm.) in length. At the localities mentioned, it was associated with *Aucella piochii* Gabb, *A. stantoni* Pavlow, and *A. hyatti* Pavlow, and on Elder Creek with *Aucella knoxvillensis*, nov., at a somewhat lower horizon.

Its occurrence in the Grindstone group has been noted in another place.

Aucella krotovi Pavlow

(Plate 6, figure 7)

Aucella krotovi PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 32, Pl. 2, figs. 31 a–c; 32 a–c; Portlandian and Aquilonian of Russia.

This species was not mentioned by Pavlow as occurring in the Knoxville of California, although he may not have had examples of it from the West Coast. Many examples of the species have been collected from beds of the Knoxville, especially from strata outcropping near Quinto Creek, Stanislaus County. These are very similar to those described by Pavlow from the Portlandian of Russia (1907, Pl. 2, fig. 31 a–c), and the identification of this unusual form seems to be well supported. The same species has been found at Blue Canyon, western Tehama County, in strata that have been assigned to the Grindstone group, and to upper-middle Portlandian, and accordingly its stratigraphic position in California seems to conform to that in Russia.

In form and outline the shell is long and relatively narrow, or tonguelike; the beak of the left valve is but little longer than that of the right valve, the dorsal and ventral borders of the valves are slightly curved or undulating from the beak to the base of the shell. No examples of this species have been found in the Elder Creek group within the type areas of the Knoxville. On Quinto Creek the species was found associated with *Aucella* cf. *bononiensis* Pavlow, *Aucella stantoni* Pavlow, *Oppelia* (*Streblites*) *quintoensis*, nov., and *Haploceras pachecoensis*, nov.

Aucella weerthi Pavlow

(Plate 10, figure 2)

Aucella weerthi PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 58, Pl. 4, figs. 13 a–c; 14 a, b; 15 a, b; lower beds of the Knoxville (in part), western Tehama County, California.

A paratype of this species illustrated by Pavlow (1907, Pl. 4, fig. 13 a–c) was said to have come from the lower beds of the Knoxville in western Tehama County, California. It is also said to resemble very closely *Aucella andersoni* Pavlow, from which it differs only in details. Should these forms prove to be identical, the name of one would become a synonym and should be dropped. Few forms have been discovered in the Knoxville series that seem to be referable to *A. weerthi*, although at least two complete examples seem to agree satisfactorily with the figures given by Pavlow.

In outline the shell of the left valve is elongate-ovate; the anterior border is roundly curved, the posterior margin is nearly straight, curving downward behind to the posterior terminus of the same. The beak is short and rather narrow and rises but little above the dorsal border of the shell. The surface is marked only by gentle concentric undulations. These examples do not, however, resemble any yet found that can be identified with *A. andersoni* as here understood, and they were found at a higher horizon than those figured as the latter. They were found at Blue Canyon, a branch of the Middle fork of Elder Creek, at Loc. 45 (Calif. Acad. Sci.) in the upper part of the Grindstone group, associated with many other species of *Aucella* characteristic of the same group.

Aucella subinflata Pavlow

(Plate 12, figure 6)

Aucella subinflata PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, Pl. 6, figs. 1 a–c; 2 a, b; 3 a–c; 4 a–c; Portlandian of Russia (zone of *P. giganteus*).

According to Pavlow (1907, p. 68) the species has a considerable stratigraphic range, and, moreover, he adds: "toward the end of the Aquilonian it is transformed into *Aucella inflata* (Toula) and becomes rare." The latter species is found only in the lower beds of the Shasta series and is regarded as characteristic of the Paskenta group in California. The only examples found by the writer that seem referable to *Aucella subinflata* Pavlow occur in the Newville group of the Knoxville. They are well represented at Loc. 28,037 (Calif. Acad. Sci.) and therefore belong in the uppermost group here regarded as of Tithonian age. The species may be recognized by its regular form, which is rather robust, by its shell, which has an almost smooth surface, and by the character of the shell itself, more easily recognized than described. The figured examples, found 1,800 feet below the top of the series, were associated with various berriasellids, including *B. storrsi* (Stanton), *Aulacosphinctes reedi*, nov., and with *Phylloceras glennense*, nov., and *P. knoxvillense* Stanton.

Aucella attenuata Anderson, n. sp.

(Plate 12, figure 4)

The shell of this species is long, narrow, inequivalve, each valve being strongly arched; the left valve, long and recurved, beak falconlike; the right valve shorter, well arched, but less so than the left; dorsal margin nearly straight in the holotype, the ventral border more rounded than the other in outline; angle at the beak about 30°; surface smooth or crossed by only concentric folds; general form narrow and much thickened vertically. The species has some resemblance to *Aucella linguiformis* Meek and possibly also to *A. arcuata* (Hyatt), from the upper part of the Mariposa beds in the Sierra Nevada, but the resemblance may be superficial only. The holotype and other examples were found at Blue Canyon, Tehama County, associated with *Aucella tenuicollis* Pavlow, much beneath the zone of *Berriasella storrsi* (Stanton), and *Phylloceras knoxvillense* Stanton, and accordingly in the Grindstone group of the series. This example (Calif. Acad. Sci. type Coll.) measures: length, 33 mm.; greatest width, 14 mm.; thickness of both valves, 15.3 mm.; found at Loc. 3,401 (Calif. Acad. Sci.) 1.5 miles northwest of Cooper's place on the south fork of Elder Creek, Tehama County.

Aucella fischeri (d'Orbigny)

(Plate 12, figures 1, 5)

Aucella fischeri, PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 58, Pl. 4, figs. 15–19 a–c; zone of *Virgatites*, upper Portlandian.

This species is found plentifully in the upper part of the Knoxville series in California, namely the Newville group, at Loc. 28,037 (Calif. Acad. Sci.) and at Loc. 28,609 (Calif. Acad. Sci.), 3.5 miles north of the Winslow bridge, western Glenn County, and also at Blue Canyon, a tributary of Middle fork of Elder Creek, Tehama County. The figured specimens were obtained at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, where it was associated with *Berriasella storrsi* (Stanton), *Phylloceras knoxvillense* Stanton, and *Bochianites glennensis*, nov. Older examples of the species are not unlike *Aucella russiensis* Pavlow, found in much lower beds in the series, but they are less smooth, and are more strongly marked by concentric folds. They have not been found in beds of older Portlandian age in the Knoxville series.

Aucella tenuicollis Pavlow

(Plate 13, figure 8)

Aucella tenuicollis PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 49, Pl. 3, figs. 4 a–c; 5 a–c; 6 a–c; 7 a–c. Aquilonian of Kachpour, Russia.

The occurrence of this species in the Knoxville beds near Paskenta was recognized by Pavlow, and it has since been found there and at other localities, namely, in the Newville group of the series and in the upper part of the Grindstone group, as at Blue Canyon, northwest of Cooper's place. It has been found in the Newville group at Loc. 28,037 (Calif. Acad. Sci.) and also in a lower zone near Mount Diablo (Bagley Creek). Pavlow has figured examples of the species found near Paskenta (Pl. 3, fig. 6 a–c). The species is found more frequently in the Newville group and seems to have been mistakenly referred to *A. piochii* Gabb, which it superficially resembles.

Pavlow remarks that neither the species nor its near relatives have been found in the Lower Cretaceous of Russia. The remark applies equally well to its occurrence in California, where its position is in the Newville group, where it is most frequently found.

Aucella terebratuloides Lahusen

(Plate 13, figure 7)

Aucella terebratuloides LAHUSEN, Mém. Comm. Géol. (Russ.), vol. 8, 1888, p. 18, 39, Pl. 4, figs. 4–8 (not 2, 3).
Aucella piochii, STANTON (in part, "var. *ovata*"), U. S. Geol. Survey, Bull. 133, 1895, Pl. 4, figs. 11–13, probably from the upper part of the Knoxville series, western Tehama County.
Aucella terebratuloides, PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 60, Pl. 5, figs. 4 a, b; 5 a, b; 6 a–c; 7 a–c; 12 a–c.

The shell of this species is robust in form, though not large, not quite smooth, usually subtriangular in outline; some of its forms resemble *Aucella subinflata* Pavlow but lack its regularly rounded form, short beaks, and broadly rounded base.

It is said to have a stratigraphic range in Russia from upper Portlandian to lower Valanginian, whereas in California its range is from the Newville group to middle Horsetown (lower Aptian), with the possible development of some varieties.

It occurs frequently in beds belonging to the lower part of the Paskenta group on McCarthy Creek and in the Newville group, as at Loc. 28,837 (Calif. Acad. Sci.) in western Glenn County. In Alaska it may have a similar range, but this has not been shown.

Aucella trigonoides Lahusen

(Plate 13, figure 4)

Aucella trigonoides LAHUSEN, Mém. Comm. Géol. (Russ.), T. 8, 1885, p. 14, 36, Pl. 2, fig. 2; figs. 21–24.—PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 85, Pl. 4, figs. 23 a–c; 34 a, b; 25 a–c; Aquilonian of Russia.

The only examples found in the Knoxville series that seem referable to this species were found at Loc. 28,037 (Calif. Acad. Sci.) in the Newville group, near the top of the series, associated with *Berriasella storrsi* (Stanton), *Aulacosphinctes reedi*, nov., and *Phylloceras knoxvillense* Stanton, in beds of Tithonian age. The figured specimen of the left valve (Pl. 13, fig. 4) has the following dimensions: length, 52 mm.; greatest width, 35 mm.; thickness, 14 mm. In this example the beak is terminal and acute but does not overhang the apex of the right valve; the ventral margin is broadly rounded, whereas the dorsal margin is nearly straight or but little curved. The right valve, belonging to a small individual, is subtriangular, the angle at the apex being about 80°. The surface is nearly smooth or marked only by concentric undulations. According to Pavlow, the species does not extend into the Cretaceous but terminates in the upper part of the Aquilonian. It greatly resembles *Aucella cascadensis* Crickmay (1932) from the "Cretaceous" near Harrison Lake, British Columbia.

Aucella occidentalis Anderson, n. sp.

(Plate 12, figure 2)

This species appears to belong to the group of *Aucella dilatata* Pavlow, but it is larger and more robust and has a more rounded beak. The left valve is rounded at and below the beak which is strongly curved downward; the right valve is somewhat triangular, much produced in front, and the apex is overhung by the rounded beak of the left valve. In general form this species resembles *Aucella okensis* Pavlow, but it is more rounded, thicker, and smoother, and lacks the strong concentric ridges of the latter. The general outline of the left valve is subovate, the broadest part being a little below the hinge, the margins of the valves converging toward a narrowly rounded posterior end of the shell.

The holotype (Calif. Acad. Sci. type Coll.) was found at Loc. 28,037 (Calif. Acad. Sci.), 6 miles north of the Winslow bridge, western Glenn County, in the Newville group of the Knoxville series, associated with *Berriasella storrsi* (Stanton), *Aulacosphinctes reedi*, nov., and forms of *Cylindro-*

teuthis and other species of *Aucella*, representing a Tithonian stage of the series. The holotype has the following dimensions: length, 50 mm.; greatest width, 35 mm.; thickness of both valves, 29.5 mm.; the angle formed at the apex of the right valve is greater than 95°. This species has not been found at any other horizon in the Knoxville series, although three good examples were found at its type locality.

Aucella pavlovi Sokolow

Pavlow has figured and described under this name specimens of *Aucella* obtained by D. Sokolow in eastern Russia, which he regarded as belonging to a lower Portlandian horizon. To the same species Pavlow also refers, without question, a right valve figured by Stanton (1895, Pl. 4, fig. 10) as representing a form of *A. piochii* Gabb, and which presumably came from lower Knoxville beds in western Tehama County. Search has been made in the Knoxville series in California for Sokolow's species, but so far without success. The form figured by Stanton, and which has been referred by Pavlow to this species, seems likely to have been the right valve of *Aucella sollasi* Pavlow, here figured from beds of the Grindstone group at the Reed quicksilver mine on Davis Creek, and at the same horizon on the South fork of Elder Creek, Tehama County. It may be added, however, that the right valve figured by Stanton seems to be only doubtfully referable to *A. piochii* Gabb, and its reference to *A. pavlovi* Sokolow seems to need confirmation by the discovery of more complete examples.

Aucella pallasi Keyserling

Aucella pallasi KEYSERLING, Reise in Petschoraland, 1864, p. 299, Pl. 16, figs. 1–6; Russia.—WHITE, U. S. Geol. Survey, Mon. 13, 1888, p. 131, Pl. 3, fig. 9; copy of Keyserling's original figure.—F. KOKEN, Leitfossilien, 1896, p. 184, Fig. 152, Lower Volga beds, Russia.

Pavlow (1907, p. 22) regards this species as a variety of ***Aucella mosquensis*** (von Buch) and omits it from a formal discussion as being distinct from it. The form figured by White, and later by Koken, has not been found by the writer in the Knoxville series in California, although certain types have been noted that seem to resemble it somewhat.

Aucella volgensis Lahusen

(Plate 10, figure 1)

Aucella volgensis LAHUSEN, Les Aucelles, 1888, p. 16, 38, Pl. 3, figs. 1–17; Lower Cretaceous, Volga basin, Russia.—PAVLOW, Nouv. Mém. Soc. Impér. des Natur. de Moscou, T. 17, 1907, p. 27, Pl. 2, fig. 10 a–c; Neocomian; lower zone with *Craspedites spaskensis* Micheil, Government of Riasan, Russia.

This species has sometimes been mentioned as occurring in California and has been thought to be a Knoxville form, but the typical form, if it occurs here at all, should be regarded as belonging to a Paskenta horizon in the Shasta series. The figured example (Pl. 10, fig. 1) was found by L. W. Henry in the Lower Cretaceous (Paskenta group) in the Arlington district on the north border of Berkeley, but it hardly conforms to the figures of *A. volgensis* given by either Lahusen or Pavlow. However, the name has been used occasionally for this or a related species form found in California, and the species may occur on the West Coast.

Aucella stantoni Pavlow

(Plate 3, figures 17–20)

Aucella piochii STANTON (not Gabb) (part), U. S. Geol. Survey, Bull. 133, 1895, p. 42, Pl. 4, figs. 6, 7 (not figs. 2–5, 8–10).
Aucella stantoni PAVLOW, Nouv. mém. Soc. impér. natur. Moscou, T. 17, 1907, p. 48, Pl. 3, fig. 3.

This species was recorded by Stanton from the South Fork of Elder Creek in the lower part of the Elder Creek group. A varietal form (Pl. 3, figs. 19, 20) was found on Bagley Creek, near Mount Diablo, in the Newville group.

Aucella hyatti Pavlow

(Plate 6, figure 3)

Aucella hyatti PAVLOW, Nouv. mém. Soc. impér. natur. Moscou, T. 17, 1907, p. 49, Pl. 3, fig. 10.

This species was based by Pavlow on American specimens. It is recorded here from the Newville group on McCarthy Creek and the Elder Creek group on the South fork of Elder Creek, Tehama County.

Aucella n. sp. A

(Plate 3, figures 15–16)

This form was found in the upper part of the Elder Creek group near or below the zone of *Kossmatia dilleri* Stanton, at the locality 1.2 miles southeast of the Kleinsorg chromite mine, on Elder Creek.

Aucella n. sp. B

(Plate 6, figure 6)

This form is reported from the Newville group at California Academy of Science locality 28,037, on Watson Creek, western Glenn County.

Class GASTROPODA

Few species of gastropods have been found in the Knoxville series, and these have been found chiefly in its uppermost group. Stanton (1895) recognized only four species belonging to four genera, and perhaps to four families, all of which were obtained from the Newville group in the vicinity of Paskenta, southern Tehama County. To this number are here added two species, two genera, and two families from the lower beds of the Newville group found in the section exposed on Redbank Creek, northern Tehama County.

As compared to the number of gastropods found in the succeeding Shasta series, those known from the Knoxville series are not many and are of somewhat more primitive stocks, as here represented. It is noteworthy that their arrival followed soon after the wide expansion of the Knoxville sea, at the epoch of maximum subsidence, and of the spread of marine waters in the Great Valley trough, and in other latitudes along the West Coast as known at the present time. These stocks appear to have arrived, as did other classes of Mollusca, at the epoch of maximum submergence along the continental border.

Family TURBINIDAE Adams

Genus *Turbo* Linnaeus

Turbo paskentaensis Stanton

(Plate 5, figures 11a, b)

Turbo paskentaensis STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 64, Pl. 12, figs. 5, 6; 3 miles northwest of Paskenta, Tehama County.

The species has been well described by Stanton and appears to need no special comment here, although it may be noted that it is one of the more abundant forms found in its type area, which

from this, and from other types described by Stanton from the same locality, indicate that it was near the shore line of its particular epoch.

Genus *Amberleya* Morris and Lycett

Amberleya dilleri Stanton

(Plate 5, figures 8a–c)

Amberleya dilleri STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 68, Pl. 12, figs. 7–9; 3 miles northwest of Paskenta, Tehama County.

As far as now known, this is the first and only appearance of this genus on the West Coast, and like the preceding species it arrived in the Great Valley trough at the time of the maximum submergence up to the date of its occurrence. The locality is one of more than ordinary interest on account of its apparent isolation from others at the time of its molluscan colonization.

Stanton's estimate as to the stratigraphic position of the locality beneath the summit of the Knoxville series appears to be reasonably correct.

Family PYRAMIDELLIDAE Gray

Genus *Hypsipleura* Koken

Hypsipleura? occidentalis Stanton

(Plate 5, figures 9a, b)

Hypsipleura? occidentalis STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 70, Pl. 13, figs. 3, 4; 3 miles northwest of Paskenta.

No examples of this species have been seen by the writer, and it appears to be rare, although it small size renders it inconspicuous, and it may be easily overlooked. As Stanton's locality appears to be of the nature of a reef, not far off shore, the species may be regarded as exceptionally rare in the Newville group.

Family CERITHIIDAE Menke

Genus *Cerithium* Adanson

Cerithium paskentaense Stanton

(Plate 5, figures 10a, b)

Cerithium paskentaensis STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 71, Pl. 13, figs. 5, 6; 3 miles northwest of Paskenta.

The remarks connected with the three preceding species apply equally to this one. The fauna found here is limited in the area occupied by it and cannot be traced more than a few hundred feet along the strike of the beds and has not been found in outcrop at any other place. Stanton gives a list of 16 species obtained from this locality, from which the richness of this horizon in molluscan life may be inferred, although relatively few have been collected, perhaps from lack of persistent search.

Family NERINEIDAE Zittel

Genus *Itieria* Matheron

Itieria californica Anderson, n. sp.

(Plate 13, figure 5)

The shell of this species is small, elongate-ovate, or biconic; spire short, body longer than the spire; surface of shell polished or showing only longitudinal lines; columella showing 5 or more flat hori-

zontally revolving plications. Only a single example of this species has been found, but its rarity in the Knoxville seems to justify a record of its occurrence here, even with the meager description of it that is now possible. The holotype (Calif. Acad. Sci. type Coll.) measures as follows: altitude (incomplete), 11 mm.; total height (est.), 13 mm.; width, 5 mm.

The species is not unlike *Itieria staszycii* Zeuscher, from the Tithonian of Inwald in the Carpathian Mountains, as figured by Zittel (1913, p. 549).

The horizon of the species is that of Loc. 28,037 (Calif. Acad. Sci.) at which it was found; it accordingly is of Tithonian age.

Incertae Sedes

Genus *Eucyclomphalus* von Ammon

Eucyclomphalus cupidoformis Anderson, n. sp.

In the original text of the preliminary paper (1933) this species was termed *Trochus cupidoformis*, nov., with some doubt. *Trochus cupido* d'Orbigny has been given the name *Eucyclomphalus cupido* (d'Orbigny) by Cossmann (1915, p. 202), who refers it to a Liassic horizon. The holotype of the present species is not well preserved and cannot be illustrated photographically, although it is not difficult to recognize its character and ornamentation with a lens. The spire is high and turbinate, with five distinct whorls that slope downward to a broadly rounded base; whorls angulated a little below the middle, with a distinct revolving ridge ornamented by flattened, not prominent spines, from which arise low ridges on the upper part of the whorl; base imperforate, rounded, crossed by beaded spiral threads that gradually diminish in strength downward.

The holotype of the species (Calif. Acad. Sci. type Coll.) was found by A. I. Gregersen and R. W. Burger in the lower part of the Newville group of the Knoxville series on Redbank Creek, Tehama County, where it was associated with a small species of *Pecten* and with *Phylloceras knoxvillense* Stanton.

Class CEPHALOPODA

Of the more than 80 invertebrate species described or listed from the Knoxville series in the present paper more than 40 are cephalopods, of which the majority are new. Of the total number 25 are ammonoids, and 15 are belemnoids, although neither list is complete. None of these can be identified with species known in the Shasta series on the West Coast or in the Lower Cretaceous anywhere. Some of them greatly resemble types known in the Jurassic of Russia or western Europe.

Many paleontologists believe that the comparatively short duration of cephalopod species render them especially valuable as chronological and therefore as stratigraphical indices wherever they are found. It is noteworthy, therefore, that they constitute so large an element in the fauna of the Knoxville series. Happily they appear in sufficient numbers and variety to determine essentially the chronological limits or span of the series as a whole, and of its more important subdivisions, and this had already been done in large part upon the basis of other types, and now confirmed by the cephalopods. It may be stated here in summary that a majority of the cephalopods now known from the Knoxville succession occur in its upper 2000 feet, and most of the remainder occur in its lower third, namely, in the Elder Creek group. Few if any cephalopods have been found in the Grindstone group which, insofar as known, is richer in pelecypods.

Berriasellids are more numerous in the upper part of the series, in the Newville group, along with various species of *Phylloceras*, *Lytoceras*, and perisphinctids. On the whole these are of such types as characterize Tithonian horizons in Europe, in India, and in Mexico and the Andean countries.

The cephalopod types found in the Elder Creek group are such as are known in the Portlandian horizons of each of these countries, though some elements in the fauna indicate an approach to older Mesozoic divisions. This is seen in the occurrence of a few types of *Belemnopsis* in the lower part of the Elder Creek group, although this part of the Knoxville succession has been but little searched. In truth the paleontologic basis for the chronological limitation of the series at the bottom is not yet precisely known, though it probably does not antedate Portlandian time.

Family PHYLLOCERATIDAE Zittel

Genus ***Phylloceras*** Suess

Phylloceras knoxvillense Stanton

(Plate 11, figure 5)

Phylloceras knoxvillense STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 72, Pl. 14, figs. 1–3 (not fig. 4); near Cooper's place on the South fork of Elder Creek, Tehama County.

This species is well described and illustrated by Stanton and needs no further comment, although a note of exception may be added. The smaller form illustrated by Stanton (Pl. 14, fig. 4), doubtfully referred by him to this species, has a very much smaller umbilicus, is flattened on the sides, and was found at a different locality and stratigraphic horizon, and in brief appears to be a distinct species, for which a new name should be supplied. *Phylloceras knoxvillense* Stanton was described from an example found in the Newville group on the South fork of Elder Creek. It has been found also on Redbank Creek at the same horizon, and on Watson Creek (Loc. 28,037, Calif. Acad. Sci.), western Glenn County, associated with a considerable fauna listed in another place, and assigned to a Tithonian horizon. *Phylloceras ramosum* Meek, to which Stanton has referred (p. 73), is confined to a Senonian horizon of the Chico series.

Phylloceras knoxvillense Stanton grew to a large size, as stated by Stanton. An incomplete example, septate throughout, has been obtained at Loc. 28,037 (Calif. Acad. Sci.) which indicates a diameter of more than 200 mm. The assemblage of species with which this form is here associated includes *Berriasella storrsi* (Stanton), many forms of *Aucella*, and *Cylindroteuthis tehamaensis*, all of which are of Tithonian aspect, as Burckhardt indicated (1930).

Phylloceras timothyi Anderson, n. name

(Plate 6, figures 1, 2)

Phylloceras knoxvillense?, STANTON, 1895, p. 73, Pl. 14, fig. 4; 3 miles northwest of Paskenta, Tehama County.

This species was doubtfully referred by Stanton to the preceding form, which in some features it resembles, but it has a relatively smaller umbilicus, is more flattened on the sides, and occurs at a different horizon, although in the Newville group of the Knoxville series. The holotype, according to Stanton, was found in the small limestone lens, 3 miles northwest of Paskenta, associated with a considerable fauna listed by Stanton (1895, p. 17), near the base of the Newville group.

Phylloceras glennense Anderson, n. sp.

(Plate 11, figures 1, 2)

This species appears to be related to *Phylloceras apenninicum* Canavari as figured by Burckhardt (1906, Pl. 18) from the upper Jurassic of Sierra de Caja, central Mexico, which has been referred to an "upper Portlandian" horizon. The form here illustrated resembles that of Burckhardt in all visible features, although it occurs in an assemblage of species that places it in a somewhat higher horizon. It appears to belong in the lineage of the Mexican form, but of this there is no positive proof at present.

In the species here described, the finer costal lines are bundled on the umbilical border and the lower part of the sides, but higher on the sides they separate and become equally spaced. Near the periphery the finer costae swing rather strongly forward and cross the ventral zone in a shallow sinus, as in *P. knoxvillense*. *Phylloceras glennense* differs from the latter in its lack of constrictions on the sides, in its somewhat finer costae, and in the bundling of these on the lower half of the sides; it is also thinner in section relative to the diameter of the whorls. The holotype (Calif. Acad. Sci.

type Coll.) has the following dimensions: greatest diameter, 85.5 mm.; greatest thickness of whorl, 19 mm.; width of umbilicus, about 10 mm. This example and others larger and smaller were found at Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County. Like the preceding species it seems to have attained a considerable size; one example almost wholly septate measures 216 mm. in greater diameter.

Phylloceras capellense Anderson, n. sp.

(Plate 4, figure 8)

A satisfactory figure of this species cannot now be given, since its holotype is a rock mold from which a plaster cast was obtained. A more complete example which forms the basis of the description was in the possession of W. B. Griffith of Napa, California, but it could not be borrowed for illustration. The form is discoidal and little inflated, and its umbilical pit is small relative to diameter. The costal lines are fine, and on the holotype they almost disappear near the umbilical border but are visible on the outer two-thirds of the side, curving strongly forward near its periphery. The holotype (Calif. Acad. Sci. type Coll.) has a maximum diameter of 80 mm. and a thickness of 12 mm. or more. It was found on Capell Creek, at the south end of Berryessa Valley, associated with *Belemnopsis berryessae*, nov., *Aucella russiensis* Pavlow, and the example owned by W. B. Griffith, mentioned above. Not far north, in the same zone, Taff and Cross obtained an example of *Aucella knoxvillensis*, nov., similar to that found at Knoxville, Napa County. The horizon of the species is Tithonian, near that of Watson Creek.

Family LYTOCERATIDAE Neumayr

Genus *Lytoceras* Suess

A few examples of *Lytoceras* have been found in the Newville group, all of which have been in a poor state of preservation, so that satisfactory descriptions can hardly be made, although mention of their occurrence should not be omitted, even though fragmentary. Little comparative material is available from the West Coast, or from other regions, although in part comparison can be made with the better preserved types found in the lower part of the Shasta series. Among the latter only a single species has any resemblance to one occurring in the Knoxville series, and this occurs in the upper part of the Paskenta (Valanginian) group. *Lytoceras saturnale* Anderson, occurring in the lowest part of the Shasta series, has no counterpart in the Knoxville series, and probably there is little relationship in any occurring in the two series.

Lytoceras aff. *L. liebigi* (Oppel)

(Plate 14, figure 1)

Lytoceras liebigi (Oppel), ZITTEL (Eastman, 1913) Textbook of Paleontology, p. 653; Tithonian; Stramberg, Moravia.

With the material and data now at hand a satisfactory comparison of this species with that of Oppel from Stramberg beds can hardly be made. In size, form, section, and ornamentation there is much resemblance, but little more than this can be said.

Lytoceras aulaeum Anderson, from the upper beds of the Paskenta group, in the Cottonwood district, shows some resemblance, though no specific relationship, and the present data do not warrant further comparison.

Lytoceras aff. *G. exoticum* Oppel

(Plate 14, figure 2)

Two fragmentary examples of a lytoceratid species nearly related to *Lytoceras exoticum* Oppel, as illustrated by Uhlig (1903) from the Chidamu beds (Spiti, Pl. 1), were collected from the dark

shales of the Newville group on Watson Creek (Loc. 28,037, Calif. Acad. Sci.), western Glenn County. The chief difference in the forms from California and the type illustrated by Uhlig appears to be in its umbilical ratio. In the form figured by Uhlig this ratio is 0.461:1, whereas that of the Newville type is 0.388:1. In the specimens found on Watson Creek there is much resemblance to *L. exoticum* in form, ornamentation, and cross section; the section of the whorl is very nearly circular, a little broader than high (ratio 23:21), the involution is slight, and the sculpture consists of fine, rounded, slightly sinuous threads, interspersed with occasional higher and stronger costae; the suture line is similar to that of Uhlig's Figure 4 c; in the Newville type the high "knife-edge" costae, such as are shown in Uhlig's restoration (1903, p. 8) do not appear, but these seem to have been lost by wear, or otherwise, as seems to have been the case in the examples figured by Uhlig (Pl. 1). The largest example of the California type indicates a diameter of more than 90 mm., although fragments of a still larger individual have been found which consist of a rock mold of an imperfect specimen about 60 mm. in diameter.

Lytoceras huberti Anderson, n. sp.

(Plate 10, figures 6a, b)

This species is represented by casts of three rather large fragments apparently belonging to a single individual shell. The species is large, broadly umbilicate, little involute; section of whorl broadly subelliptical, dorso-ventral diameter greater than the lateral; surface generally smooth or marked by inconspicuous transverse, rounded ribs not evenly spaced but crossing the periphery with a slight forward curve; all the fragments are septate throughout. The holotype (Calif. Acad. Sci. type Coll.) is the smaller specimen, having the following dimensions: dorso-ventral diameter, 70 mm.; lateral diameter, 56 mm.; suture line as shown in the figure; apparent diameter of entire whorl, not less than 200 mm.

This species closely resembles and appears to be related to *Lytoceras sutile* (Oppel) Steuer, from the upper Jurassic of Cieneguita, western Argentina. These examples were found by Hubert O. Jenkins of the Junior College, Sacramento, and in recognition of his enthusiastic co-operation in the exploration of the belt of the Knoxville series it should bear his name. All the fragments were found together at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County. The holotype is the best preserved, though not the largest fragment.

Family Berriasellidae Spath, 1923

Genus *Aulacosphinctes* Uhlig, 1910, emend. Spath, 1931

Although Uhlig (1903, vol. 4, p. 158, 159) placed *Aulacosphinctes* as a subgenus under *Perisphinctes* (Waagen), he nevertheless recognized the fact that some forms of *Berriasella* Uhlig have perisphinctid characters. Spath (1931, p. 540) goes further and says: "The separation of *Berriasellidae* from *Perisphinctidae*, is purely artificial, and prompted by systematic considerations" and adds that they do not represent a "cryptogenetic stock." Accordingly Spath includes in his Berriasellidae forms of *Aulacosphinctes*, placing in it *Aulacosphinctes occultefurcatus* (Waagen). Following this precedent we may also place in this family other allied species, including those described in the following pages from the Knoxville series in California.

Aulacosphinctes reedi Anderson, n. sp.

(Plate 7, figure 3; Plate 6, figure 10)

The shell of this species is characterized by its gently rounded sides, rounded but slightly flattened periphery, moderately broad umbilicus, with steep walls; sides heavily costate; ribs arising on the umbilical wall with a forward curve, rising on the side almost vertically at first, curving a little forward near the middle of the side, and more strongly above it; ribs sparingly tuberculate, having

an elongated swelling (bulla) at the umbilical border and a few small and acute nodes near the middle of the side; ribs sometimes branching at the umbilical border, sometimes single; ribs rounded, separated by rounded hollows, continuing across the periphery but dividing near, below, or above the middle of the side; sides crossed by broad constrictions, between which are about 7 normal ribs. The species appears to be closely related to *Perisphinctes* (*Aulacosphinctes*) *torresianus* Burckhardt, found near Torres, central Mexico, which, according to Burckhardt, belongs to the group of *Perisphinctes transitorius* Oppel. The species may also be compared to *Protothurmannia rezanoffiana* Crickmay, described from upper Jurassic beds in southern San Luis Obispo County, from which it differs in some important details of sculpture. The holotype (Calif. Acad. Sci. type Coll.) is a fragment consisting of about one-third of a whorl, having the following dimensions: total length, 100 mm.; greatest height of whorl, 37 mm.; apparent thickness, 28 mm.; number of primary ribs, 24; number on the periphery, 48; estimated diameter of whorl, 112 mm.; estimated width of umbilicus, 48 mm.; locality of discovery, Loc. 28,037 (Calif. Acad. Sci.) Watson Creek, western Glenn County. It occurs in the Newville group of the Knoxville series associated with many Tithonian species. The species is named in recognition of the interest and co-operative spirit of Dr. Ralph D. Reed, of the Texas Company, and in remembrance of the valuable work contributed by him and his associates to the cause of stratigraphic geology in California, and of aid to the writer of this paper.

Aulacosphinctes jenkinsi Anderson, n. sp.

(Plate 13, figure 3)

This species is largely based upon rock molds, from which plaster casts have been made, showing the essential form and sculpture, especially of the sides and umbilicus. The molds of this species cover a large part of one whorl and a part of another whorl, apparently belonging to the same individual. The thickness of the shell is not well shown, although it was discoidal, and the sides moderately inflated; umbilicus rather broad, walls abrupt; ribs thin and elevated, the number apparently about 40, arising on the umbilical wall, crossing the rounded border and the lower half of the sides with a forward, and then a backward inclination, branching near the middle of the side into two and occasionally three costae; interspaces broader than the ribs, rounded at bottom; ribs bearing elevated nodes at the points of division.

The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: greatest diameter, 43 mm.; height of last whorl, 23 mm.; width of umbilicus, 12 mm.; section of whorl, not exceeding 7.5 mm. in thickness.

The species appears to be closely related to *Perisphinctes praeneocomiensis* Behrendsen, as figured by Steinmann (1929), from the upper Jurassic of Peru. The holotype was found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, western Glenn County.

Aulacosphinctes taffi Anderson, n. sp.

(Plate 7, figures 4a, b)

The shell of this species is small, discoidal, compressed; sides flattened, but a little inflated; umbilicus narrow, walls steep, rounded above; involution moderate, costate, ribs 28 in number on a single whorl, arising on the umbilical wall, nearly straight on the sides of the whorl but curving gently forward upon nearing the periphery; costae dividing near the middle of the side, tuberculate at the outer termini of the ribs and also at points of division; some ribs simple; ventral zone narrow and concave in younger whorls, marked by ventro-lateral nodes; costae bearing a few distinct tubercules on the umbilical border. The nearest foreign analogue of the species appears to be *Aulacosphinctes occultefurcatus* (Waagen), as figured by Spath (1933), from the Umia of Cutch, India. The holotype (Calif. Acad. Sci. type Coll.) is a young adult example, having the following dimensions: greatest diameter, 20 mm.; height of whorl, 9 mm.; thickness of whorl, 7 mm.; width of umbilicus, 7 mm. This example was found at Loc. 28,037 (Calif. Acad. Sci.) on Grindstone Creek, 1,200 feet west of the iron bridge on the Winslow-Newville road, western Glenn County. It was found asso-

ciated with *Lytoceras* aff. *L. exoticum*, *Protacanthodiscus* sp., *Inoceramus stantoni* nov., and *Aucella stantoni* Pavlow, in the upper part of the Newville group of the Knoxville series.

Aulacosphinctes diabloensis Anderson, n. sp.

(Plate 2, figure 2)

In the collections of the Academy of Natural Sciences of Philadelphia sent to the California Academy of Sciences for study, there is an immature perisphinctid ammonite, bearing the label "D," contained in a tray with a number of specimens of *Aucella*, including *A. piochii* Gabb, from a locality near Mount Diablo, Contra Costa County. This material was left at the Philadelphia Academy by Gabb during the 1860's. It now seems probable that the initial "D" was intended to indicate "Diablo" and that Gabb had so labeled it, though this is not now known.

This ammonite has a diameter of 18.6 mm. and a thickness of 6 mm.

The ammonite resembles a young specimen of *Aulacosphinctes*, of the type of *Aulacosphinctes* sp. figured by Imlay (1939, Pl. 15, figs. 10, 11) from Sierra de Jimulco, Coahuila, Mexico, which appears to be of Tithonian age, as does also the fauna from Mount Diablo. At all events, without further evidence, the ammonite in question may be provisionally so recorded until further data concerning it are obtained.

Aulacosphinctes? colusaensis Anderson, n. sp.

(Plate 13, figures 1, 2)

A fragment of a perisphinctid shell, consisting of about one-third of a whorl, was found by C. M. Cross on the west side of Bear Creek, about 1.3 miles above the mouth of Sulphur Creek, western Colusa County. The shell is of medium size, discoidal, compressed, with broad umbilicus and almost smooth sides, showing only depressed tabular costae; section of whorl narrowly elliptical, with abrupt umbilical walls; sides sloping gently to a narrowly rounded ventral border. The holotype (Calif. Acad. Sci. type Coll.) measures as follows: length of fragment, 63 mm.; width, 25 mm.; greatest thickness, 12 to 13 mm.; estimated diameter of entire whorl, 68.5 mm. The suture, only partly exposed, is relatively simple, having rather long trifid lobes, with narrow and sharp terminations, rather broad, rounded saddles, with spatulate subdivisions. Its horizon is believed to be middle Portlandian, probably 1,500 feet above the lowest beds exposed on Bear Creek, Colusa County.

Berriasella storrsi (Stanton)

(Plate 7, figure 1)

Hoplites storrsi STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 79, Pl. 17, figs. 1, 1a; a mile northwest of Cooper's place on the South fork of Elder Creek, Tehama County.
Berriasella storrsi, BURCKHARDT, Mém. Soc. Paléont. Suisse, vol. 49, 50, 1930, p. 63, 71.

According to Stanton (1895, p. 80) the group to which this species belongs "is represented in the Upper Jurassic (Tithonian) by a number of species, such as *H. calisto* d'Orbigny, *H. carpathicus* Zittel, and others that have a close resemblance to our species."

The example of *Berriasella storrsi* here figured was found at Loc. 28,037 (Calif. Acad. Sci.) 6 miles north of Winslow bridge, western Glenn County, where it was associated with *Phylloceras knoxvillense* Stanton, *P. glennense*, nov., *Aulacosphinctes reedi*, nov., and many other species characteristic of the Newville group, here regarded as Tithonian. From Stanton's account this species is associated with *P. knoxvillense*, *Cylindroteuthis tehamaensis* (Stanton), and *Aucella piochii* Gabb, in a stratigraphical horizon on the South fork of Elder Creek near that of Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, Glenn County.

The generic name *Stenoceras* was used by Uhlig (1911, p. 354) for *Hoplites storrsi* Stanton and *H. angulatus* Stanton and was subsequently mentioned by Spath (1923, p. 306; 1925, p. 145; 1931, p. 546) for the same species. However, d'Orbigny (1849, p. 287) had used the name *Stenoceras* for

species already placed in *Bactrites*, and *Stenoceras* Uhlig is unavailable. The two species display differences from *Berriasella* and *Subthurmannia* and might usefully be placed under a distinctive generic name, but the writer prefers for the present to leave *storrsi* under *Berriasella*. Similar species include "*Berriasella?*" *coahuilensis* Imlay (1939, p. 53) and "*Thurmannites?*" *duraznensis* Gerth and "*Tt.*" *discoidalis* Gerth (1925, p. 97, 98).

Genus *Protothurmannia* Crickmay, 1932

Protothurmannia rezanoffiana Crickmay

(Plate 4, figure 10)

Protothurmannia rezanoffiana CRICKMAY, Am. Mid. Nat., vol. 13, 1932, p. 2, Pls. 1, 2; Alamo Creek, San Luis Obispo County.

According to Crickmay this genus is placed under Berriasellidae and is thus related to *Aulacosphinctes* Uhlig, some forms of which it resembles. As shown by the figures and the description given by the author, the species is discoidal, flattened on the sides, rounded on the periphery, and rather broadly umbilicate, walls of the umbilicus abrupt, rounded on the borders; sides and ventral surface costate, the costae arising on the umbilical walls, branching from nodes or bullae on its borders and also near the middle of the sides, slightly sinuous; sides crossed by broad transverse grooves; secondary costae arising either as divisions of the principal ribs or as intercalated ribs. At a diameter of 72 mm. there are 13 primary and 27 secondary ribs in a quadrant of the whorl. The holotype has the following dimensions: diameter, 92 mm.; thickness, 25 mm. (?); width of umbilicus, 33 mm.; height of whorl, 37 mm.; umbilical ratio, 0.358:1.

The associated species, as given by the author, are: *Berriasella* cf. *calisto* (d'Orbigny), *Substeueroceras* sp., *Crioceras* sp., *Bochianites* sp., *Lytoceras* sp., *Pachyteuthis* sp., *Aucella terebratuloides* Lahusen. As all these species have representatives in the upper part of the Knoxville series (Newville group), in its type area, as at Loc. 28,037 (Calif. Acad. Sci.) in western Glenn County, there can be no doubt that the horizon of the species and its associated forms is the same—namely, that of the Newville group.

Genus *Kossmatia* Uhlig, 1903

Kossmatia tehamaensis Anderson, n. sp.

(Plate 2, figures 1a–c)

A well-preserved but fragmentary example of *Kossmatia* was discovered in the upper part of the Elder Creek group of the Knoxville series, about 4500 feet above its base, near the South fork of Elder Creek (SE ¼ sec. 14, T. 24 N., R. 7 W.). This discovery in the lower part of the Knoxville series, made by Robert L. Rist, is of more than ordinary importance, being the first example of this genus found in the Knoxville of California. The species is of moderate size, discoidal, a little compressed, moderately involute, broadly umbilicate, strongly costate, with sulcate periphery; umbilical walls steep, rounded on the border; shell costate, with ribs arising at the umbilical suture, curving backward on the walls, but on the umbilical border and sides inclining a little forward, dividing at or a little below the middle of the side or above it, and curving strongly forward near the ventral zone; ribs interrupted at the median plane and slightly offset.

The holotype (Univ. Calif. type Coll.) was found at Loc. A-2921 (Univ. Calif. Coll.) and has the following dimensions: greatest diameter, 48 mm.; height of whorl, 18 mm.; thickness of whorl, 13 mm.; width of umbilicus, 20 mm.; ribs rounded and uniform, without tubercules, some ribs single, but more often divided into two or even three branches. The species greatly resembles *Kossmatia victoris* Burckhardt (not *Proniceras victoris*) (1906, Pl. 36, figs. 10–15), described from beds near Santa Rosa, central Mexico, which Burckhardt assigned to a middle Portlandian horizon. The species differs from *K. victoris* Burckhardt in the curvature of its ribs, which branch lower on the side of the whorl, and in the more distinct interruption of the ribs in the ventral zone and in its more decided ventral groove.

Kossmatia kleinsorgensis Anderson, n. sp.

(Plate 2, figure 3)

This species is known only from fragments of a shell found in the dark shales of the Elder Creek group of the Knoxville on the north branch of the South fork of Elder Creek, about 4000 feet above its base and a mile or more east of the Kleinsorg chromite mine. The shell is small, broadly umbilicate, little involute, with depressed whorls, which are broader than high; section of whorl reniform; shell numerously costate, with branching ribs, bearing small tubercules at the points of division; ribs arising at the umbilical suture, curving strongly forward, bifurcating on the lower part of the side, passing without interruption across the ventral zone but forming an angle of about 90° at its median line; ventral groove shallow but distinct.

The holotype (Calif. Acad. Sci. type Coll.) is a fragment of an outer whorl, with a portion of an inner whorl, having the following dimensions: length, 23 mm.; greatest width, 10 mm.; greatest height, 6.2 mm.; apparent diameter of whorl, not less than 27 mm. These fragments were found in a concretionary lens of limestone within the dark shales, about 1 mile south of the Soledad ranch house. Its horizon is near that of *Kossmatia tehamaensis*, nov. Not far south of its point of discovery and in the same zone were found *Aucella soledadensis*, nov. and a fragment of a belemnite.

Kossmatia dilleri (Stanton)

(Plate 10, figures 5a, b)

Hoplites dilleri STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 82, Pl. 18, figs. 6, 7; 3 miles west of Lowreys, Tehama County.

Kossmatia dilleri, BURCKHARDT, Inst. Geol. de México, Bol. 29, 1912, p. 132, 133, 224; assigned to an upper Portlandian (Tithonian) horizon.

According to the field position of its point of discovery, as given by Stanton (1895, p. 82), as well as by its character, this species appears to belong near the middle of the Elder Creek group of the Knoxville series. Quoting directly from Stanton's account (p. 82):

"Shell small, discoid, somewhat involute; whorls convex on the sides, flattened on the periphery, and regularly rounded to the broad umbilicus, whose diameter is a little more than one-third of that of the entire shell; surface ornamented by numerous slender but sharply elevated ribs that rise in the umbilicus, are almost straight for about two-thirds of the distance across the whorl, and then divide, sometimes into two, but more frequently into three, branches that curve strongly forward and are interrupted by a narrow furrow on the rather broad abdomen".

This example was found associated with *Aucella terebratuloides* Lahusen, as determined by Pavlow. Its stratigraphic position is probably in the upper part of the Elder Creek group of the Knoxville series.

Genus *Substeueroceras* Spath, 1923

Substeueroceras stantoni Anderson, n. sp.

(Plate 11, figures 3, 4; Plate 15, figure 3)

The holotype and other examples here figured were found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek. The holotype (Pl. 15, fig. 3) resembles and is related to *Berriasella calisto* (d'Orbigny), as figured by Kilian (1893, p. 646, Pl. 5). The whorls are discoidal, subquadrate in section, little involute; umbilicus broad; periphery a little sulcate; umbilicus moderate, walls steep; ribs, about 52 to 56 in number, arise at the umbilical suture, incline slightly backward on the wall, but on the sides rise from the umbilical border at nearly right angles, rarely dividing below the middle of the side, but above the middle are dichotomous; the ribs at first narrow, with thin edges and concave interspaces, but after division becoming rounded, with narrow interspaces; suture lines comparatively simple. The species resembles a form figured by Shimizu (1928) from the Torinosu limestone of

Japan, under the name *Perisphinctes* (*Aulacosphinctes*) cf. *P. steigeri* Shimizu. The holotype (Calif. Acad. Sci. type Coll.) is incomplete and is not known to include the body whorl. It has the following dimensions: greatest diameter, 51 mm.; maximum thickness, 12.8 mm.; height of whorl, 22.8 mm.; width of umbilicus, 17.8 mm. Two other fragmentary but smaller examples were found at the same locality. All were associated with *Berriasella storrsi* (Stanton), *Phylloceras glennense*, nov., *P. knoxvillense* Stanton, and other species of the Newville group.

Genus *Proniceras* Burckhardt

Proniceras sp.

(Plate 14, figure 3)

A large fragment of a perisphinctid shell was found at Loc. 28, 609 (Calif. Acad. Sci.) 3.5 miles north of the Winslow bridge, near the Alder Springs road. By its form, ribbing, and suture line, as far as exposed, the species appears to belong in the lineage of *Proniceras*, resembling in many features *Proniceras jimulcense* Imlay (1939, pl. 18, figs. 1, 2), described from the Casita formation (*Substeueroceras* beds), Coahuila, central Mexico. In form the shell is discoidal, flattened on the sides; section of whorl somewhat lenticular, heavily costate; ribs arising in thickened bullae on the umbilical border, branching near the middle of the side into two or three smaller costae, gently curving forward, not well shown in the figure. The figured example was found associated with another perisphinctid shell and with *Aucella* aff. *hyatti* Pavlow, *Inoceramus scotti* nov., and other invertebrates, in the upper part of the Newville group, and it is regarded as of Tithonian age.

Genus *Durangites* Burckhardt, 1912

Durangites aff. *D. vulgaris* Burckhardt

(Plate 2, figure 4)

Durangites vulgaris BURCKHARDT, Inst. geol. Mexico, Bol. 29, 1912, p. 149, Pl. 37, figs. 1–36; Pl. 38, figs. 1–4; upper Portlandian.

This specimen was found near the South fork of Elder Creek, east of Lowry road, Tehama County.

Genus *Distoloceras* Hyatt, 1900

Distoloceras sp.

(Plate 14, figure 4)

A fragmentary specimen referred to *Distoloceras* was found on Grindstone Creek, 1200 feet west of the iron bridge, associated with a *Protacanthodiscus*. It is probably of Tithonian age.

Subfamily OPPELIINAE Haug

Genus *Oppelia* (*Streblites*) Hyatt

Oppelia (*Streblites*) *quintoensis* Anderson, n. sp.

(Plate 6, figures 9a, b, c)

The shell of this species is small, discoidal, compressed, with a very small umbilicus and a narrowly rounded ventral border. Four good examples and some fragments of whorls representing this species were found by Allan Bennison near Hawk Rock, north of Quinto Creek, western Stanislaus County, associated with *Haploceras* sp., *Aucella krotovi* Pavlow, *A. stantoni*, and *A. andersoni* Pavlow. The

shell is smooth, showing only lines. The holotype (Calif. Acad. Sci. type Coll.) measures: greatest diameter, 13 mm.; greatest thickness, 3.5 mm.; sides sloping gently toward the periphery. A fragment of a whorl belonging to a larger example, wholly septate, has a diameter of 15 mm. The species resembles *Oppelia* (*Streblites*) *durangensis* Burckhardt from the Upper Jurassic beds in the vicinity of San Pedro del Gallo, central Mexico.

Family HAPLOCERATIDAE Zittel

Genus ***Haploceras*** Zittel

Haploceras pachecoense Anderson, n. sp.

(Plate 6, figures 8a, b)

The shell of this species is small, discoidal, a little inflated, little involute; surface smooth, or marked only by broadly sinuous lines which begin on the umbilical walls, rise on the sides with a forward inclination, become vertical at the middle of the side, and above it swing gently forward and form on the periphery a shallow backward sinus; costal lines rather widely spaced, with smooth interspaces, marked by only fine lines of growth; umbilicus small, with steep walls and a rounded border; sides inflated, sloping toward the periphery; section of whorl as broad as high, semielliptical. The holotype (Calif. Acad. Sci. type Coll.) measures: total diameter, 21 mm.; height of whorl, 10 mm.; thickness of whorl, 10 mm.; width of umbilicus, 4 mm.

This species somewhat resembles *Haploceras indicum* Uhlig (1903), from the middle part of the Spiti shales of Chojano, India, but it is relatively thicker and more robust in form.

The holotype was found by Allan Bennison, about 1000 feet south of Hawk Rock, Pacheco Pass quadrangle, associated with the preceding species, *Aucella krotovi*, and *A. stantoni* Pavlow, and others in the middle Portlandian of the Knoxville series.

Genus ***Protacanthodiscus*** Kilian

Genotype, *Protacanthodiscus andraei* Kilian

Protacanthodiscus crossi Anderson, n. sp.

This species is known only from fragments whose holotype (Calif. Acad. Sci. type Coll.) was found by C. M. Cross and J. A. Taff at Loc. 28,667 (Calif. Acad. Sci.) on McCarthy Creek, Tehama County, 3 miles northwest of Paskenta, in the upper beds of the Knoxville series. The whorls are subquadrate in section, broader than high, involution about one-fifth the height of the whorl; whorl costate, with two kinds of ribs, major and minor; the coarser ribs crossing the ventral zone tuberculate and spine-bearing; spines on the ventral border elevated and pointed; tubercules near the middle of the side, low and obtuse; minor ribs much reduced and irregular, intervening between the major ribs. In young stages of growth the ribs bear only ventro-lateral tubercules, between the rows of which the ventral zone is smooth. The sutures are not exposed. The species occurs with *Aucella terebratuloides* Lahusen, *Aucella hyatti*, *Inoceramus* aff. *I. ovatus* Stanton, and a species of *Anomia*. The same or a nearly related species has been found on Grindstone Creek, Glenn County, at Loc. 28,037 (Calif. Acad. Sci.) with *Aulacosphinctes taffi*, nov., and *Inoceramus stantoni*, nov. The horizon is in the upper part of the Newville group of the Knoxville series and is regarded as Tithonian.

INCERTAE SEDES

Genus ***Bochianites*** Lory, 1898

Bochianites glennensis Anderson, n. sp.

(Plate 7, figure 2)

This species is known only from fragmentary examples of the shafts of two individuals found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, Glenn County. The holotype (Calif. Acad. Sci.

type Coll.) is the larger of these, measuring as follows: length, 44 mm.; greatest diameter, 10 mm.; the section is elliptical, the dorsoventral diameter exceeding the transverse. The sides of the shaft are marked by numerous oblique, rounded ribs or costae which slant forward from the dorsal border; dorsum slightly flattened, crossed by costae at right angles to the median plane; some of the ribs are relatively heavy, between which are finer threads crossing the anterior part of the shaft at the same oblique angle as the ribs. The shaft is slightly curved and tapers gradually toward the distal end. This species differs much from that found in the Shasta series in western Tehama County and described by the writer (1938), being more robust, more narrowly elliptical, and possessing a curved rather than a straight shaft. Crickmay has mentioned the occurrence of the genus in the Tithonian beds of southern San Luis Obispo County, in the Nipomo quadrangle.

Genus *Aptychus* Meyer

Aptychus? knoxvillensis Stanton

(Plate 11, figures 7, 8)

Aptychus? knoxvillensis STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 83, Pl. 18, figs. 1, 2; near Knoxville, Napa County.

Stanton's figures and account of this species constitute the only recorded information now available concerning its systematic place and its stratigraphic position in the column of the Knoxville series. The specimen upon which his description was based was found on the road from the Reed to the Ryal quicksilver mines, north or northwest of Knoxville. Stanton only doubtfully referred the species to this genus, and concerning the example found he says in part:

"In the single specimen collected the two valves join each other at an angle of about 60°. Only one valve is preserved so as to show the entire outline, which is elongate-subquadrate, resembling some of the simpler forms of Perna. The surface is marked by obscure concentric undulations".

The species was found associated with *Aucella piochii* Gabb in beds exposed between the Reed quicksilver mine and Knoxville, in which area no strata are seen in the outcrop older than the Grindstone group, and to the upper part of this group the species is here tentatively assigned. The strata exposed at the Reed mine are not older than the Grindstone group as determined stratigraphically, and those exposed at Knoxville are clearly within the Newville group, from which facts it is inferred that the horizon of the present species is probably in the upper part of the Grindstone group, though it may be younger.

Suborder BELEMNOIDEA

The systematic study of the several families, genera, and species of belemnoids found in the Mesozoic of the West Coast has not yet progressed far beyond the stage of their general recognition by the pioneer paleontologists and geologists who were required to deal with them. For this reason their stratigraphic distribution was not well known, and in truth neither their systematic determination nor their stratigraphic positions are yet fully known. Accordingly, their usefulness in stratigraphic determination cannot yet be regarded as well established, except as to a few characteristic genera known in the Knoxville and Lower Cretaceous series. In the Mesozoic of Europe and of other regions in which belemnoids have been found in great numbers, hundreds of forms have been described. Paleontologists who have given them most attention have believed that the vertical range of their species is not great and that their usefulness should be more fully recognized. The guards of belemnoids, which constitute almost their only remains, are comparatively simple in structure and form and accordingly are less diversified than the shells of ammonoids and other invertebrates. However, many differences in structure, size, form, and proportions are now recognizable by specialists and constitute criteria for generic and specific differences, as with other invertebrates, and their usefulness should not be underestimated. Their study in various provinces has shown that their remains are capable of much stratigraphic utility, at least within the provinces where they

are best known, and it is believed that they should be useful in interprovince correlation, although the extent to which this may be applied may not equal that of ammonoids. It is with the intent to contribute such information as it is possible to gather at this time, concerning their various types, vertical distribution, and succession that the earlier and following studies have been made. It will be seen that insofar as their study has progressed there is cause for much confidence in their stratigraphic utility throughout the West Coast, and their utility for international correlation, though yet unknown, may ultimately be very great.

It will be seen that the belemnites of the Knoxville series are of Upper Jurassic types and differ greatly from those in the Shasta series, as should be expected, and to this extent at least their utility is as great as that of any other type of cephalopod.

Family BELEMNITIDAE de Blainville

Genus *Cylindroteuthis* Bayle and Zeiler, emend. Stolley

According to Stolley (1920) this genus is wholly of Jurassic age, ranging from Lower Dogger to Upper Malm (Tithonian), but not higher. Many species belonging to this genus have been collected from the Knoxville series in California, nearly all of which have been found in the upper 2000 feet of the series, although some may range lower. Many of them are referable to the group represented by its genotype, *Cylindroteuthis puzosianus* (d'Orbigny), as will be seen later. Other types of belemnites have been obtained, the stratigraphic position or range of which has not yet been definitely determined, and for this reason some reserve is felt, but for this genus in the Knoxville series its range appears at present to be confined to the Newville group. No species of belemnites have yet been discovered in the Grindstone group. In the Elder Creek group only a few and, frequently broken, guards have been found, the better preserved of which are referable to the genus *Belemnopsis*, as will be seen later.

Cylindroteuthis tehamaensis (Stanton)

Belemnites tehamaensis STANTON, U. S. Geol. Survey, Bull. 133, 1895, p. 84, Pl. 19, figs. 1–3; near Cooper's, South fork of Elder Creek, Tehama County.
Acroteuthis tehamaensis, STOLLEY, Foss. Catal., pt. 2 (Von Bulow-Trummer), 1920, p. 212.
Oxyteuthis tehamaensis, CRICKMAY, Canad. Field Nat., vol. 47, 1933, p. 14.

This species has been well figured and described by Stanton and needs no further description at this time, although the following notes may be offered as aiding in establishing its stratigraphic horizon as well as its taxonomic position. Its generic assignment is here based upon its analogy with the genotype given by Stolley. Stolley is also the author of *Acroteuthis*, the genotype of which is *Acroteuthis subquadratus* (Roemer), in which the lateral diameter of the guard is greater than the dorsoventral; the leading forms are stout, with rapidly tapering apex; the ventral area is usually marked by a deep groove, although this feature does not appear to be constant.

Stolley's assignment of this species was regarded as doubtful by Stolley himself, and it may have been due to a misconception as to its character or to its stratigraphic position as given in its description. Stanton had compared his species with two forms previously known—namely, *Belemnites inequilateralis* Eichwald and *Belemnites obeliscoides* Pavlow. The first of these Stolley refers to *Duvalia* d'Orbigny, and the latter to *Cylindroteuthis*, making it a near relative to if not synonymous with *Cylindroteuthis obelisca* Philippi.

Four good though not quite complete examples of *Cylindroteuthis tehamaensis* are in the collections of the California Academy of Sciences, all of which were found at Loc. 28,037 (Calif. Acad. Sci.), where many other species of this genus have also been found.

This species has also been obtained from a locality near that of Stanton's type, and also on McCarthy Creek. It has not been authentically reported or found at any place in the Shasta series and it is believed to be confined to the Newville group of the Knoxville series.

Cylindroteuthis occidentalis Anderson, n. sp.

(Plate 8, figures 1, 2)

In this species the guard is very long and relatively thick, tapering from near the middle with a gentle curve to an acute point; the section is subcircular, the dorsoventral diameter being slightly greater than the lateral; the ventral zone is marked by slightly flattened surface showing a little below the phragmacone, but which near the apex becomes a shallow groove.

The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length, (incomplete), 191 mm.; dorsoventral diameter, 22.5 mm.; lateral diameter, 21 mm. The paratype (Calif. Acad. Sci. type Coll.) is also incomplete but is larger, having the following dimensions: length, 175 mm.; dorsoventral diameter, 24 mm.; lateral diameter 22 mm. Had this example been complete its length would have been 220 mm. Both specimens were obtained at Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County, in the Newville group of the Knoxville series. This is the largest species of belemnite yet found in the series. It greatly resembles "*Acroteuthis*" *magnifica* (d'Orbigny), as figured by Pavlow and Lamplugh (1891, Pl. 2) from the shales at Speeton, England. Stolley refers this species to *Acroteuthis*, although according to his own indication (1920, p. 206) this genus is characterized by a lateral diameter greater than the dorsoventral, which seems to be the case in the genotype *B. subquadratus* Roemer, as shown by Pavlow and Lamplugh (1891, Pl. 3, fig. 5). However, the evident relationship of the present species to others with which it is associated clearly places it with them in the genus *Cylindroteuthis*.

Cylindroteuthis knoxvillensis Anderson, n. sp.

(Plate 9, figure 2; Plate 10, figure 4a)

The guard of this species is very long and narrow, having sides nearly parallel on the anterior half, tapering uniformly to an acuminate point behind; section of guard subelliptical, the dorsoventral diameter greater than the lateral; ventral side of the guard slightly flattened below the middle, not sulcate; sides of phragmacone converging to an angle of 27.3°, nearly central axis slightly inclined toward the ventral side. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (incomplete), 178 mm.; estimated total length, 203 mm.; dorsoventral diameter (near middle of phragmacone), 18 mm.; lateral diameter, 15 mm. The paratype (Calif. Acad. Sci. type Coll.) measures: length, 162 mm.; dorsoventral diameter, 15 mm. Three examples of this species, including the holotype, were found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County, associated with the preceding species and with *Phylloceras glennense*, nov., *Berriasella storrsi* (Stanton), and other invertebrates. This species resembles *C. klamathonae*, nov., described below, but it lacks the ventral groove, plainly seen on the latter. In general outline it resembles *Cylindroteuthis baculus* Crickmay (1930, fig. 4) from a locality near Harrison Lake, British Columbia, with which Crickmay has compared *C. tehamaensis* (Stanton). It appears to be more nearly related to *C. obeliscoides* Pavlow and Lamplugh, from the upper Jurassic (Bed F) of the Speeton Section, England, from which it differs in the absence of a decided ventral flattening near the apex, in the more nearly central position of the axis, and in the ratio of the diameter to the length. It differs from *C. tehamaensis* (Stanton) in its greater length, more gradual taper, and its sharply visible ventral flattening.

Cylindroteuthis glennensis Anderson, n. sp.

(Plate 9, figure 1; Plate 10, figure 3)

The guard of this species resembles that of *C. knoxvillensis* nov., but it is stouter and has a more distinct groove on its ventral side; in section it is subcylindrical and in its anterior half has nearly parallel sides; in its posterior half they taper to an acuminate point; ventral surface marked by a flattened zone on its anterior part that passes into a more distinct groove behind extending to the apex. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (not quite

complete), 176 mm.; dorsoventral diameter, near anterior end, 21.6 mm.; lateral diameter, 20 mm. The paratype (Calif. Acad. Sci. type Coll.) measures: length (incomplete), 165 mm.; dorsoventral diameter, 18 mm.; lateral diameter, 16 mm.; ratio of diameter to length, 0.1:13.1. Both examples were found at Loc. 28,037 (Calif. Acad. Sci.), 6 miles north of the Winslow bridge, western Glenn County, associated with the preceding species and with *Berriasella storrsi* (Stanton), *Phylloceras glennense*, nov., and many other species. This species differs from *C. knoxvillensis* nov. as shown in the figure in its thicker section, and from *C. porrectus* (Phillips) in fewer characters, except size and relative diameter. Its horizon is that of *Berriasella storrsi* (Stanton) and *Aulacosphinctes reedi*, nov.

Cylindroteuthis newvillensis Anderson, n. sp.

(Plate 9, figure 4)

A nearly complete example of the guard of this species was found by J. A. Taff and C. M. Cross, 2 miles south of Paskenta, at Loc. 28,628 (Calif. Acad. Sci.), southern Tehama County. This example is the holotype of the present species (Calif. Acad. Sci. type Coll.). The guard has the following dimensions: length, 112 mm.; maximum diameter, 13 mm.; section of same, ovate-cylindrical, slightly flattened on the sides in its middle portion; ventral side marked by a short and narrow groove. The guard tapers but little above the lower third, in which the sides converge rapidly to a rather blunt point; ventral groove extending only 23 mm. from the apex. The field position of the point of discovery places it in the Newville group of the series near its top. The same species has been found in nearly the same horizon a little south of Newville, on the road to Chrome, Glenn County.

Cylindroteuthis klamathonae Anderson, n. sp.

(Plate 8, figure 4)

The guard of this species is very long and slender, with sides nearly parallel to about the middle; posterior half tapering uniformly to an acuminate point; section of guard subelliptical, notably at the anterior end, but more nearly cylindrical near the middle and in the posterior half; dorsoventral diameter at the anterior end greater than the lateral; ventral side flattened at the anterior end but marked by a broad and shallow sulcus behind; sides and dorsum rounded and smooth; phragmacone central, axis subcentral behind, a little nearer the ventral side. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (incomplete), 162 mm.; dorsoventral diameter at bucal end, 16 mm. This example was found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County, associated with other species of the genus. It resembles *C. tehamaensis* (Stanton) but it is relatively longer, more slender, and has a more uniform taper in its posterior half and a more pronounced subelliptical section. It was included without a specific name in a former list (1933, p. 1251) from this locality. It greatly resembles *C. puzosiana* (d'Orbigny), which has been taken as the genotype of *Cylindroteuthis* by Bayle and Zeiler. A close analogue of this species is *C. obeliscoides* Pavlow, which, according to Stolley (1920), is synonymous with *C. obelisca* Phillips. The holotype of *C. klamathonae* if complete would equal in length the genotype of *Cylindroteuthis* figured by Pavlow and Lamplugh (1891–1892).

Cylindroteuthis porrectiformis Anderson, n. sp.

(Plate 9, figure 3)

The guard of this species is long and slender, tapering but little in its anterior three-fourths; section of guard nearly circular; sides nearly parallel in its major part, tapering more rapidly in its posterior fourth to an acuminate point; ventral surface flattened on the forward half, sulcate in its posterior part by a well-developed groove; phragmacone and axis nearly central; axis not well exposed. The holotype of this species consists of the latter half of the guard (Pl. 9, fig. 3a); the para-

type is the anterior half of another individual (Pl. 9, fig. 3b); both have nearly the same diameter. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length, 78 mm.; diameter at forward end, 12 mm. The paratype measures: length, 74 mm.; diameter, 12 mm.; total length of guard (est.), 143 mm., excluding the overlap shown in the figure. The species greatly resembles *C. porrectus* Phillips, as figured by Pavlow and Lamplugh (1891–1892) from the shales at Speeton, England. This example is the nearest known analogue of the holotype. The examples here figured were found together at Loc. 28,037 (Calif. Acad. Sci.) 6 miles north of the Winslow bridge, western Glenn County, associated with the preceding species and with many other invertebrate species included in the earlier lists. The species is believed to be distinct from that at Speeton, England, although the resemblance is close, and its horizon may be approximately the same.

Cylindroteuthis clavicula Anderson, n. sp.

(Plate 9, figure 5)

The guard of this species is long and relatively very slender, tapering uniformly to a slightly rounded point; the anterior end and the phragmacone are not known; the axis is central; the section of the guard is nearly circular but flattened on the ventral surface in its anterior half and marked by a distinct groove in its posterior part, not reaching the apex. Two other examples of the same species show an open alveolar pit.

The holotype (Calif. Acad Sci. type Coll.) has the following dimensions: length (incomplete), 82 mm.; lateral diameter at anterior end, 6 mm.; a second example, nearly as long, has a guard of the same diameter.

These examples were found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County. The species resembles and is probably closely related to "*Belemnites*" *macritatis* White (1884, p. 14), from Fossil Point, Port Moller, on the Alaskan Peninsula, collected by W. H. Dall, 1874, which may also represent approximately the same horizon. The present species differs from that of Port Moller in the possession of a ventral groove and a more pointed apex.

Genus *Acroteuthis* Stolley, 1911

The genus *Acroteuthis* Stolley, which is well represented in the Shasta series in California and in Oregon, has only a single species in beds known to be referable to the Knoxville series. It is quite unlike any species known in the Shasta series of California, and some hesitation is felt as to its generic lineage.

Acroteuthis? watsonensis Anderson, n. sp.

(Plate 8, figure 3)

Two incomplete examples of this species were found at Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, 6 miles north of the Winslow bridge, western Glenn County, associated with many other species of cephalopods and *Aucella*. The holotype (Calif. Acad. Sci. type Coll.) has a length of 91 mm., a maximum diameter of 23 mm., and a section very nearly circular. The dorso-ventral diameter is slightly less than the lateral; the ventral side is marked by a flattened zone extending the whole length of the guard, which is incomplete but possesses a narrow groove near its apex; sides converging but little on the higher part of the guard, as seen in the holotype; sides on the lower part of the guard sloping rapidly to the apex, which forms a rather blunt point. This species may be regarded as forming an approach to *Acroteuthis explanatoides* Pavlow and Lamplugh (1891–1892), although it differs in some details. The examples found were associated with *Phylloceras glennense*, nov., *Berriasella storrsi* (Stanton), and *Aulacosphinctes reedi*, nov. in the Newville group.

Genus ***Belemnopsis*** Bayle

Group of ***B. canaliculatus*** Schlotheim

Belemnopsis californicus Anderson, n. sp.

(Plate 1, figure 1)

The guard of this species is of moderate size and relatively short and stout; section subcylindrical, slightly flattened on the sides and dorsum; ventral side marked by a flattened zone in its forward portion, but having a shallow groove behind; axis subcentral, situated a little nearer the ventral side of the guard; dorsal side smooth; alveolus not exposed. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (not quite complete), 95 mm.; dorso-ventral diameter, 17 mm.; lateral diameter, 14 mm.

The guard of this species is unlike any other found in the Knoxville series or on the Pacific Coast, insofar as known. The example was found by the writer in the dark sandy shales of the Elder Creek group in the lower part of the Knoxville on Toms Creek, Tehama County, about 2000 feet stratigraphically above its base, at Loc. 28,603 (Calif. Acad. Sci.), near the horizon of *Aucella* aff. *A. bononiensis* Pavlow.

Belemnopsis tomsensis Anderson, n. sp.

(Plate 1, figure 5)

The guard of this species is relatively small and more slender than that of the preceding form, although in length and section it bears some resemblance to it. The holotype (Calif. Acad. Sci. type Coll.) is slightly flattened on the sides; section of guard subcircular, the ventral side bearing a faint groove on its posterior half; guard tapering to a slender point; alveolus not well exposed. The holotype measures as follows: length (incomplete), 76 mm.; dorsoventral diameter, 10 mm.; lateral diameter, 9 mm.; alveolar portion obscure. This example was found in the dark shales in the lower part of the Elder Creek group of the series about 2500 feet above its base on Toms Creek, by J. B. Johnson, of Corning, California.

Belemnopsis? napaensis Anderson, n. sp.

(Plate 2, figure 7)

This species greatly resembles *Belemnites russiensis* (d'Orbigny) as figured by Pavlow and Lamplugh (1891, Pl. 6). It is rather slender in form, slightly fusiform, tapering gradually from the middle of the guard to an acuminate apex; section of guard cylindrical, slightly flattened on the ventral side; phragmacone central, axis subcentral; dorsum seemingly arched longitudinally; ventral side straight; walls of alveolus converging at an angle of about 26 degrees. The holotype (Calif. Acad. Sci. type Coll.) was found by N. L. Taliaferro 3 miles north of Knoxville, Napa County, in the upper part of the Knoxville series, where it was associated with *Aucella hyatti*, *A. russiensis* Pavlow, and other invertebrate forms. The holotype has the following dimensions: length of guard, 95 mm.; greatest diameter, near bottom of alveolus, 11 mm. The forward two-thirds of the guard tapers regularly below the alveolus. The assignment of this form to a subgenus of *Belemnites* cannot now be made.

Belemnopsis mercurialis Anderson, n. sp.

(Plate 1, figure 2)

The guard of this species is of moderate size, slightly compressed in the dorsoventral diameter, especially at its anterior end, giving the guard a fusiform appearance when viewed from the side,

not properly belonging to it throughout; posterior half of the guard tapering gradually to an acuminate point; alveolar area subelliptical in section, perhaps due to rock pressure; latter half of the guard subcircular in section; axis nearly central; ventral side of guard flattened throughout the forward half but not sulcate in any part. The species has some resemblance to *Belemnopsis californicus* in size and general form but possesses a more acuminate apex and a different section.

The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (not wholly complete), 102 mm.; dorsoventral diameter at anterior end, 12 mm.; lateral diameter, 13 mm. est.). This example was found by N. L. Taliaferro 3 miles north of old Knoxville, associated with the preceding and with other congeneric species and with *Aucella hyatti* and *A. russiensis* Pavlow, in the upper part of the Knoxville series.

Belemnopsis? berryessae Anderson, n. sp.

(Plate 2, figure 8)

This species is known from only a single incomplete example obtained from the shales of the lower Newville group on Capell Creek, at the south end of the Berryessa Valley, Napa County. The guard is incomplete, retaining only its central portion, which shows it to have unusual length as compared to other types of the genus, and slightly fusiform in outline, tapering gradually to its anterior end, and more rapidly toward the apex; ventral side marked by a slight groove near the bucal end, which merges into a flattened surface near and below the middle of the guard; section subcircular, the dorsoventral diameter being slightly greater than the lateral; axis central, as seen at the ends of the holotype. This example (Calif. Acad. Sci. type Coll.) was found in the dark shales exposed in the bed of Capell Creek, near the bend, where a well had been drilled for oil and a tunnel had been driven into the bank. It was associated with *Aucella russiensis* Pavlow, *A. knoxvillensis*, and *Phylloceras capellense*, nov., and other species characteristic of the Newville group. The holotype has the following dimensions: length, 74 mm.; greatest diameter, near middle of guard, 9 mm.; diameter at bucal end, about 7 mm.

Belemnopsis cachensis Anderson, n. sp.

(Plate 1, figure 6)

Three examples of this species differing in size were found on Davis Creek, a tributary of Cache Creek, at Loc. 28,807 (Calif. Acad. Sci.), 3 miles north of Knoxville, and a mile or more east of the old Reed quicksilver mine, northern Napa County, by N. L. Taliaferro and party, and were donated to the California Academy of Sciences. The holotype (Calif. Acad Sci. type Coll.) has the following dimensions: length (incomplete), 56 mm.; greatest diameter, 9 mm.; paratypes, measuring respectively 34 and 30 mm. The holotype consists of the posterior half of the guard, which tapers at an increasing rate to a rather blunt point; ventral surface slightly ridged, with a flattened zone on either side, giving the guard a slightly quadrate section, which otherwise is subcylindrical, with a distinct ventral groove. These examples were associated with the preceding, *Aucella russiensis* Pavlow, and *Aucella hyatti* Pavlow.

Belemnopsis spiculoides Anderson, n. sp.

(Plate 1, figure 3)

This unusually small species is known only from two well-preserved examples found at Loc. 28,807 (Calif. Acad. Sci.), 3 miles north of Knoxville, Napa County, by N. L. Taliaferro and party, associated with the preceding species and with *Aucella hyatti* and *A. russiensis* Pavlow, in the upper part of the Knoxville series (Newville group).

The holotype, the larger of the two examples (Calif. Acad. Sci. type Coll.), has the following dimensions: length (incomplete), 41 mm.; greatest diameter, 4 mm.; diameter at top, 2 mm. The paratype (Calif. Acad. Sci. type Coll.) measures: length, 27 mm.; greater diameter, 4 mm. This is

the smallest species of the genus known from the Knoxville series. The guard is fusiform, tapering toward both ends but more rapidly toward the apex; surface smooth, showing only a slight flattening on the ventral side and a faint groove near the apex.

Genus ***Hibolites*** Montfort

Hibolites wilburensis Anderson, n. sp.

(Plate 2, figures 5, 6)

This species is closely related to *Hibolites conradi* Kilian, from the upper Tithonian strata of Andalusia, Spain, although probably not identical with it. The guard is short, fusiform, tapering uniformly toward both ends; apex subacuminate or even blunt; anterior end not well preserved; section nearly circular; axis subcentral; ventral surface marked by a slight groove, not reaching the apex. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length, 71 mm.; greatest diameter, 13 mm.; paratype (Calif. Acad. Sci. type Coll.) is represented by only the posterior part of the guard, showing no forward taper but a uniform slope toward the apex. These examples were found in the sandy shales of the Knoxville near the mouth of Sulphur Creek, Colusa County, by N. L. Taliaferro and students. The stratigraphic relations of the beds exposed here show that they form the local base of the group, and the known fauna supports this view. The following species have been collected from these beds by Taff, Cross, and the writer: *Aucella bononiensis* Pavlow, *Aucella* aff. *A. mosquensis* (von Buch), and *Aulacosphinctes colusaensis* Anderson, nov.

Hibolites arroyoensis Anderson, n. sp.

(Plate 1, figure 4)

The guard of this species is of moderate size or small, somewhat fusiform, terminating behind in a rapidly tapering shaft to a rather blunt point; section of guard subcircular near the middle, flattened at the anterior end in a dorsoventral direction; phragmacone and axis central; ventral surface marked by a faint ridge along its median line; dorsal side rounded uniformly. The holotype (Calif. Acad. Sci. type Coll.) measures: length (incomplete), 73 mm.; greatest diameter, 11 mm. The paratype (Calif. Acad. Sci. type Coll.) measures: length, 47 mm.; greatest diameter, 10 mm. These examples were found on the east side of Davis Creek at Loc. 28,807 (Calif. Acad. Sci.) by N. L. Taliaferro and his students and were donated to the Academy of Sciences. They were found associated with *Aucella russiensis* Pavlow, and *A. hyatti* Pavlow and are regarded as representing the upper part of the Newville group.

Hibolites toroensis Anderson, n. sp.

(Plate 4, figure 9)

The guard of this species is of moderate size, long, relatively slender, tapering uniformly and gently toward both ends from its middle; section of guard subelliptical, having a dorso-ventral diameter shorter than the lateral; apical end broken but terminating in a rather blunt point. The holotype (Calif. Acad. Sci. type Coll.) has the following dimensions: length (est.), 100 mm.; greatest diameter, near middle of guard, 12 mm.; lateral diameter at buccal end, 10 mm.; dorso-ventral diameter, 8 mm.; ventral side marked by a shallow groove near the buccal end; posterior half tapering to a long point. This example was found by N. L. Taliaferro on Old Creek, sec. 30, T. 28 S., R. 11 E., in San Luis Obispo County, in the lower part of the Toro formation (San Luis Folio), associated with *Aucella* aff. *A. sollasi* Pavlow, *Aucella* sp., *Turbo* sp., and other species of *Hibolites*, one of which resembles *Hibolites* of the group of *H. hastatus* (Blainville). The horizon is believed to be that of the Newville group, and its age Tithonian.

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EXPLANATION OF PLATES

PLATE 1.—UPPER JURASSIC BELEMNITES FROM CALIFORNIA

Figure

(1) *Belemnopsis californicus* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); (*a*) ventral side; (*b*) the same, dorsal side; (*c*) cross section; length, 96 mm.; diameter, 17 mm. Lower beds of the Elder Creek group, Toms Creek, Tehama County. (P. 990.)

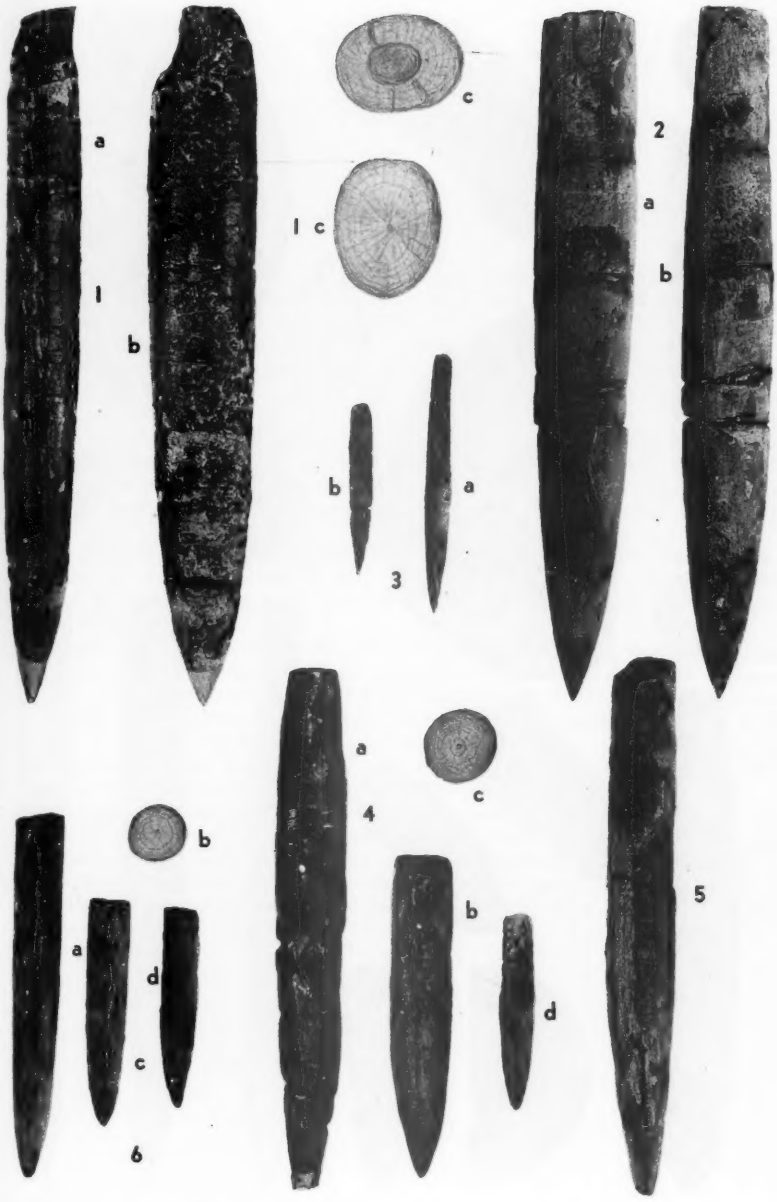
(2) *Belemnopsis mercurialis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); (*a*) dorsal view; (*b*) ventral view; (*c*) cross section of the guard; length, 102 mm.; maximum diameter, 14 mm. Newville group, Loc. 28, 607 (Calif. Acad. Sci.), 3 miles north of old Knoxville mining camp, northern Napa County. (P. 990.)

(3) *Belemnopsis spiculoides* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.); length, 41 mm.; maximum diameter, 4 min.; (*b*) paratype; length, 27 mm.; Loc. 28, 607. 3 miles north of Knoxville, Napa County; holotype and paratype found together. Upper part of Newville group. (P. 991.)

(4) *Hibolites arroyoensis* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.); length (incomplete), 73 mm.; greatest diameter, 10 mm.; (*b*) paratype, length, 47 mm.; found with holotype; (*c*) cross section of holotype; (*d*) smaller example of the same, found with the above. Loc. 28,607 (Calif. Acad. Sci.), 3 miles north of Knoxville, northern Napa County. (P. 992.)

(5) *Belemnopsis tomsensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); length, 76 mm.; greatest diameter, 10 mm. Lower beds of Elder Creek group, 1.5 miles west of Paskenta, on Toms Creek, Tehama County. Portlandian. (P. 990.)

(6) *Belemnopsis cachensis* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.); length (incomplete), 56 mm.; greatest diameter, 9 mm.; (*b*) cross section of holotype; (*c*) paratype (Calif. Acad. Sci. type Coll.); length, 34 mm.; (*d*) smaller example of same species. Loc. 28,607 (Calif. Acad. Sci.), 3 miles north of Knoxville, in Newville group. Tithonian. (P. 991.)



UPPER JURASSIC BELEMNITES FROM CALIFORNIA

UPPER JURASSIC FOSSILS FROM CALIFORNIA

PLATE 2.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

(1) *Kossmatia tehamaensis* Anderson, n. sp.; (*a*) holotype (Univ. Calif. type Coll.), with branching ribs, side view; (*b*) same, oblique view of ventral zone, showing sulcus; (*c*) central portion of suture line. Loc. A-2921 (Univ. Calif. type Coll.); about 4,575 feet above base of Elder Creek group, near South fork of Elder Creek, Tehama County. (P. 981.)

(2) *Aulacosphinctes diabloensis* Anderson, n. sp.; holotype (Acad. Nat. Sci. Phila. type Coll.), probably Loc. 27,846 (Calif. Acad. Sci.), on Bagley Creek, Contra Costa County; enlarged, 2.25 times. (P. 980.)

(3) *Kossmatia kleinsorgensis* Anderson, n. sp.; fragmentary holotype; (*a*) oblique view, showing ventral groove and forward slanting ribs; (*b*) oblique side view, showing ribs arising in umbilical bullae; length of holotype, 23 mm. Locality, 1 mile east of Kleinsorg chromite mine, near upper branch of South Fork of Elder Creek, Tehama County. Portlandian. (P. 982.)

(4) *Durangites* aff. *D. vulgaris* Burckhardt; (*a*) right side view, showing relative width of umbilicus; (*b*) view of ventral zone, showing interruption of ribs at median plane. Loc. 29,694 (Calif. Acad. Sci.), near South fork of Elder Creek, east of Lowry road, Tehama County. Portlandian. (P. 983.)

(5, 6) *Hibolites wilburensis* Anderson, n. sp.; (5 *a*) holotype (Calif. Acad. Sci. type Coll.), natural size, showing lower half of guard; (5 *b*) cross section of guard, by reflection; (6 *a*, *b*) paratype, partly eroded at top; length, 72 mm.; greatest diameter, 12 mm.; found with holotype. Near mouth of Sulphur Creek, Colusa County, in upper part of Knoxville series. (P. 992.)

(7) *Belemnopsis? napaensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type coll.); (*a*) ventral side, showing slight flattening; (*b*) left side; natural size. Loc. 28,607 (Calif. Acad. Sci.), 3 miles north of Knoxville, Napa County. Newville group, Tithonian. (P. 990.)

(8) *Belemnopsis berryessae* Anderson, n. sp.; holotype, without apical end (Calif. Acad. Sci. type Coll.); natural size; length (incomplete), 74 mm. greatest diameter, 9 mm. Cappell Creek, south end of Berryessa Valley, Napa County; Newville group, Tithonian. (P. 991.)

(9, 10) *Aucella sollasi* Pavlow; (9) left valve of concentrically ribbed form; (10) left valve of narrow, smooth form. Old grade above the Reed mine, northern Napa County, natural size. Grindstone group. (P. 965.)

PLATE 3.—UPPER JURASSIC AUCELLAE FROM CALIFORNIA

Figure

(1–5) *Aucella piochii* Gabb; (1) copy of Gabb's figure, 1864, pl. 20, fig. 173, probably Bagley Creek, near Mount Diablo. (2, 3) Topotypes of same; (2) left valve, side view; (3) front view of same, showing beak bent down by rock pressure. (4, 5) Smaller topotypes of same, showing left and right valves of normal young example. Loc. 27,846 (Calif. Acad. Sci.), Bagley Creek, north side of Mount Diablo. Newville group, Tithonian. (P. 964.)

(6, 7) *Aucella gabbi* Pavlow; copied from Stanton's figures, 1895, pl. 4, figs. 2, 5. South fork of Elder Creek, Tehama County; lower part of Elder Creek group, Portlandian. (P. 965.)

(8–11) *Aucella sollasi* Pavlow; (8) left valve of broad form; South fork of Elder Creek, near Pellow's place, Sec. 34, T. 24 N., R. 7 W.; (9) right valve of same. (10, 11) Left valves of smaller form, from old grade above the Reed mine, northern Napa County. Grindstone group. (P. 965.)

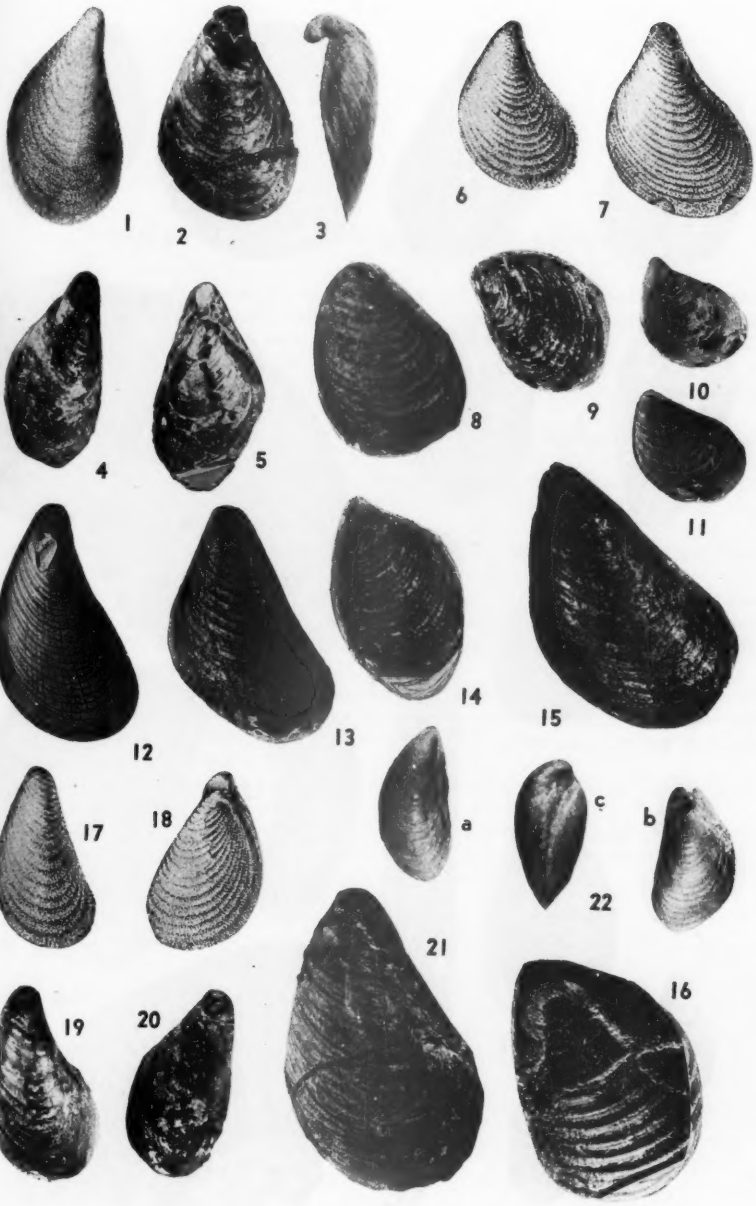
(12–14) *Aucella knoxvillensis* Anderson, n. sp.; (12) copy of White's figure of *Aucella "errington*i Gabb", 1888, pl. 4, fig. 18; near Knoxville, Napa County. (13, 14) Left and right valves of same; Loc. 29,694 (Calif. Acad. Sci.), South fork of Elder Creek, near "Hull's gate". (P. 966.)

(15, 16) *Aucella* n. sp. A; (15) left valve; (16) right valve, enlarged ×3. 1.2 miles southeast of Kleinsorg chromite mine; upper part of Elder Creek group; near or below zone of *Kossmatia dilleri* (Stanton). (P. 973.)

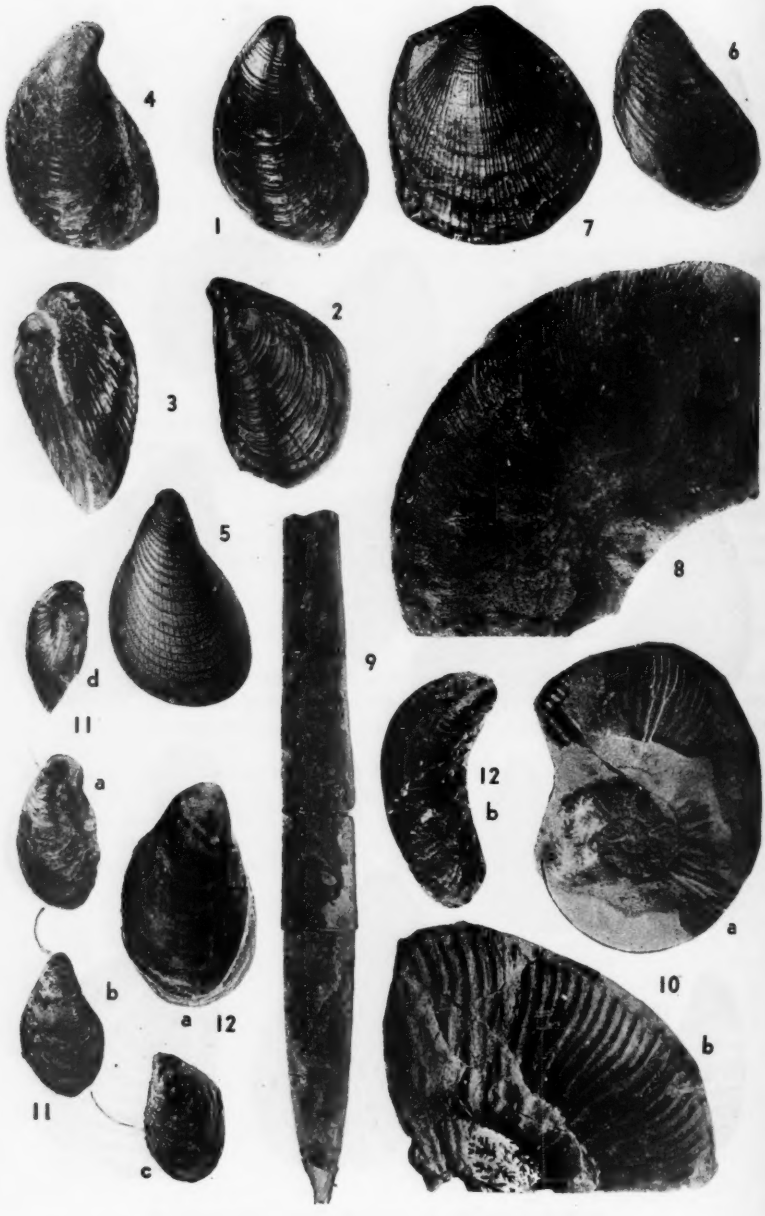
(17–20) *Aucella stantoni* Pavlow; (17, 18) copies of Stanton's figures, 1895, pl. 4, figs. 6, 7; South fork of Elder Creek; Elder Creek group, in the lower part of the same. (19, 20) Varietal form of the same species; Bagley Creek, near Mount Diablo; Newville group, Tithonian. (P. 972.)

(21) *Aucella russiensis* Pavlow; left valve, natural size. Loc. 27,486 (Calif. Acad. Sci.), Bagley Creek, Contra Costa County. (P. 968.)

(22) *Aucella gracilis* Pavlow; (*a*) left valve; (*b*) right valve; (*c*) rear view, showing both valves and thickness of the specimen. Loc. 27,486 (Calif. Acad. Sci.), Bagley Creek, near Mount Diablo; Newville group. (P. 967.)



UPPER JURASSIC AUCELLAE FROM CALIFORNIA



UPPER JURASSIC FOSSILS FROM CALIFORNIA

PLATE 4.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

(1-4) *Aucella elderensis* Anderson, n. sp.; (1) holotype (Calif. Acad. Sci. type Coll.), left valve, showing nearly straight posterior border; (2) right valve of same, showing faint striations; (3) front view of both valves, showing high arch of left valve; (4) left valve of a broader form of same species. Loc. 29,694 (Calif. Acad. Sci.), on South Fork of Elder Creek, near "Hull's gate". (5) Figure given by White of *Aucella* "erringtoni Gabb" (1888, pl. 4, fig. 19), near Knoxville. (P. 967.)

(6) *Aucella knoxvillensis* Anderson, n. sp. 1 mile north of Knoxville, Napa County; Newville group, Tithonian. (P. 966.)

(7) *Pecten (chlamys) risti* Anderson, n. sp.; holotype (Univ. Calif. type Coll.). Loc. A-2921, in upper part of Elder Creek group; 4,500 feet above base of Elder Creek group, near South fork of Elder Creek, Tehama County. (P. 962.)

(8) *Phylloceras capellense* Anderson, n. sp.; plaster cast made from rock mold. Cappell Creek at south end of Berryessa Valley; lower part of Newville group. (P. 977.)

(9) *Hibolites toroensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); natural size; length, 100 mm.; greatest diameter, 12 mm., Toro formation upper part of Knoxville series, probably from Newville group, Tithonian; Olal Creek, sec. 30, T. 28 S., R. 11 E., San Luis Obispo County. (P. 992.)

(10) *Protothurmannia rezanoffiana* Crickmay; after Crickmay (1932, pls. 1, 2) (figures reduced); diameter of holotype, 92 mm.; thickness of whorl, 25 mm. Alamo Creek, tributary of Cuyama River, southern San Luis Obispo County; lower part of Newville group, Tithonian. (P. 981.)

(11, a-d) *Aucella* aff. *A. bononiensis* Pavlow. 0.3 of a mile south of the mouth of Sulphur Creek, Colusa County, in upper part of Knoxville series. (P. 967.)

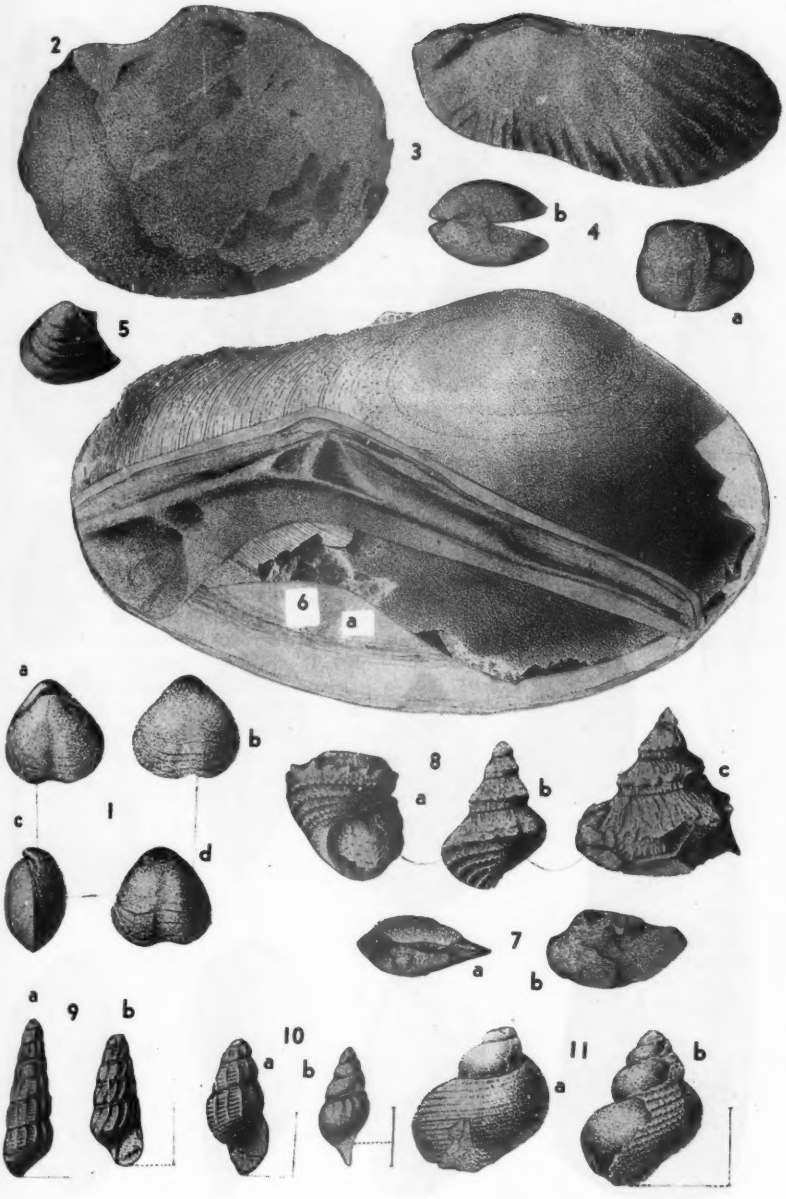
(12) *Aucella* aff. *A. mosquensis* (von Buch); left valve; (*a*) side view, natural size; (*b*) rear view, showing high arch of left valve. 1.5 miles southwest of Chrome, western Glenn County, in lower part of the Elder Creek group; Portlandian. (P. 966.)

PLATE 5.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

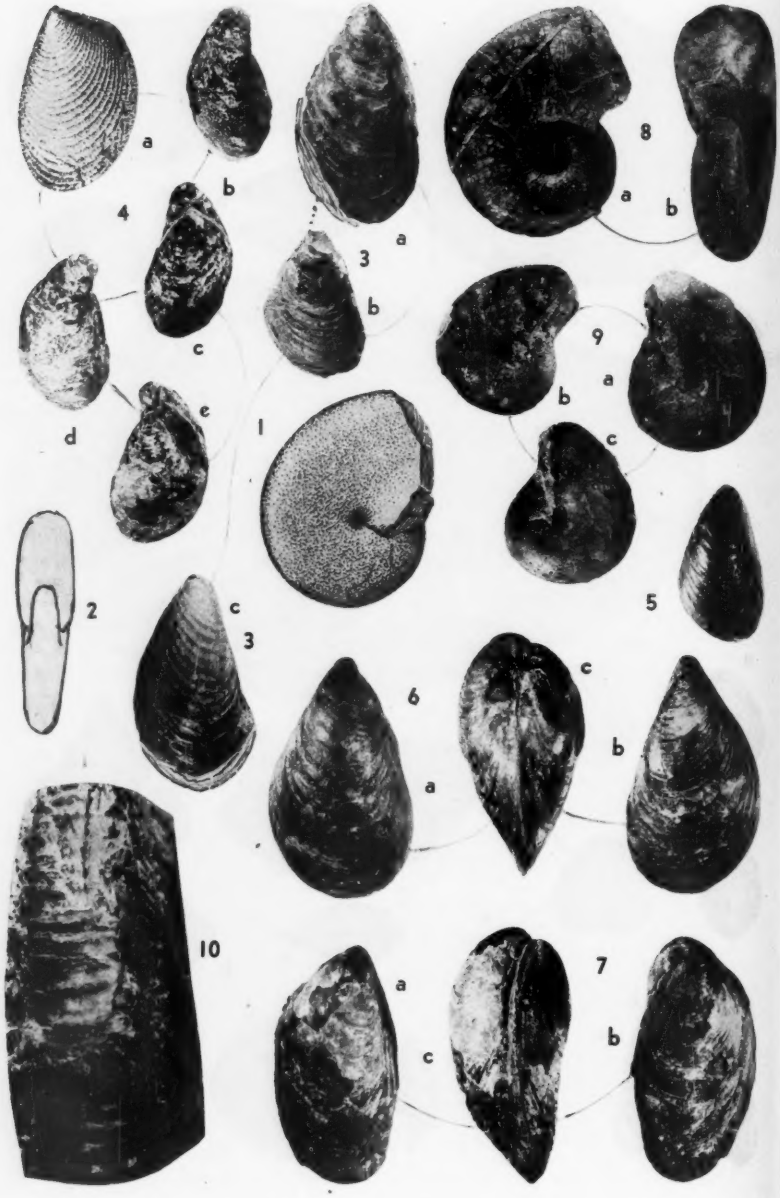
Fossils from limestone lens, 3.7 miles northwest of Paskenta, Tehama County, after Stanton (1895). Upper part of Newville group.

Figure

(1 a–d) *Rhynchonella schucherti* Stanton (p. 31, pl. 1, figures 1–4).
(2) *Lucina ovalis* Stanton (p. 59, pl. 12, figure 1). (P. 961.)
(3) *Solemya occidentalis* Stanton (p. 55, pl. 10, figure 2). (P. 961.)
(4) *Nucula gabbi* Stanton (p. 51, pl. 6, figures 11, 12). (P. 961.)
(5) *Corbula? persulcata* Stanton (p. 61, pl. 11, figure 3). (P. 961.)
(6 a) *Cardiniopsis unioides* Stanton (p. 55, pls. 8, 10, figs. 1). (p. 961.)
(7 a, b) *Nucula storrsi* Stanton (p. 52, pl. 6, figures 13, 14). (P. 961.)
(8 a–c) *Amberleya dilleri* Stanton (p. 68, pl. 12, figures 7, 8, 9). (P. 974.)
(9 a, b) *Hypsipleura? occidentalis* Stanton (p. 70, pl. 13, figures 3, 4). (P. 974.)
(10 a, b) *Cerithium paskentaensis* Stanton (p. 71, pl. 13, figures 5, 6). (P. 974.)
(11 a, b) *Turbo paskentaensis* Stanton (p. 64, pl. 12, figures 5, 6). (P. 973.)



UPPER JURASSIC FOSSILS FROM CALIFORNIA



UPPER JURASSIC FOSSILS FROM CALIFORNIA

PLATE 6.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

(1-2) ***Phylloceras timothyi*** Anderson, n. name. (1) Copy of Stanton's figure (1895, pl. 14, figure 4), provisionally figured as *Phylloceras knoxvillensis* Stanton; (?) 3 miles northwest of Paskenta. (2) Section drawn from another example, Newville group, Knoxville series. (P. 976.)

(3) ***Aucella hyatti*** Pavlow; (*a*) Newville group, McCarthy Creek; (*b*, *c*) Elder Creek group, South fork of Elder Creek, Tehama County. (P. 973.)

(4) ***Aucella andersoni*** Pavlow; (*a*) reproduction of Stanton's figure (1895, pl. 4, fig. 6, identified by Pavlow, 1907); (*b*, *c*) left and right valves of two examples from Quinto Creek, Stanislaus County. (P. 968.)

(5) ***Aucella*** cf. ***A. bononiensis*** Pavlow, natural size, left valve; Quinto Creek, Stanislaus County, associated with *Oppelia* (*Streblites*) sp. (P. 968.)

(6) ***Aucella*** n. sp. B; (*a*) left valve, showing outline, form, and surface undulations; (*b*) right valve, showing relative length; (*c*) rear view of same. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, Western Glenn County; Newville group. (P. 973.)

(7) ***Aucella krotovi*** Pavlow; (*a*) left valve; (*b*) right valve; (*c*) rear view, showing curvature and thickness of valves; figures enlarged, only slightly. Near Hawk Rock, north of Quinto Creek, Stanislaus County, in Knoxville series. (P. 968.)

(8) ***Haploceras pachecoense*** Anderson, n. sp.; (*a*) right side; (*b*) oblique view of front; found with preceding; figure enlarged ×2. (P. 984.)

(9) ***Oppelia*** (***Streblites***) ***quintoensis*** Anderson, n. sp.; (*a*) Holotype, diameter, 13 mm.; thickness, 3.8 mm.; (*b*, *c*) paratype (Calif. Acad. Sci. type Coll.); greatest diameter 12 mm.; thickness, 2.5 mm.; found with the preceding; all figures enlarged. (P. 983.)

(10) ***Aulacosphinctes reedi*** Anderson, n. sp., an oblique view of a portion of the periphery of a whorl, showing a flattening of the ventral zone. Loc. 28,037 (Calif. Acad. Sci. type Coll.), western Glenn County; Newville group, Tithonian. (P. 978.)

PLATE 7.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

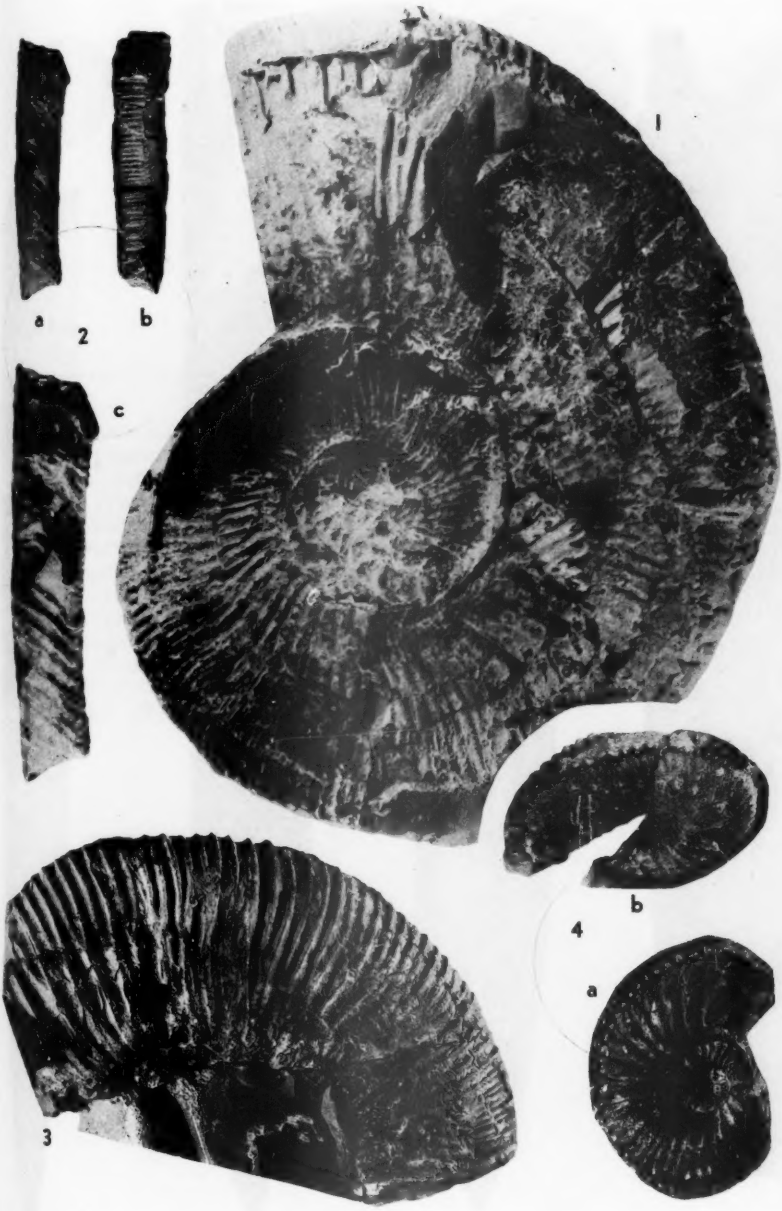
Figure

(1) *Berriasella storrsi* (Stanton); side view of an almost complete example; plesiotype (Calif. Acad. Sci. type Coll.). Loc. 28,037 (Calif. Acad. Sci.), upper part of Newville group on Watson Creek, western Glenn County; Tithonian. (P. 980.)

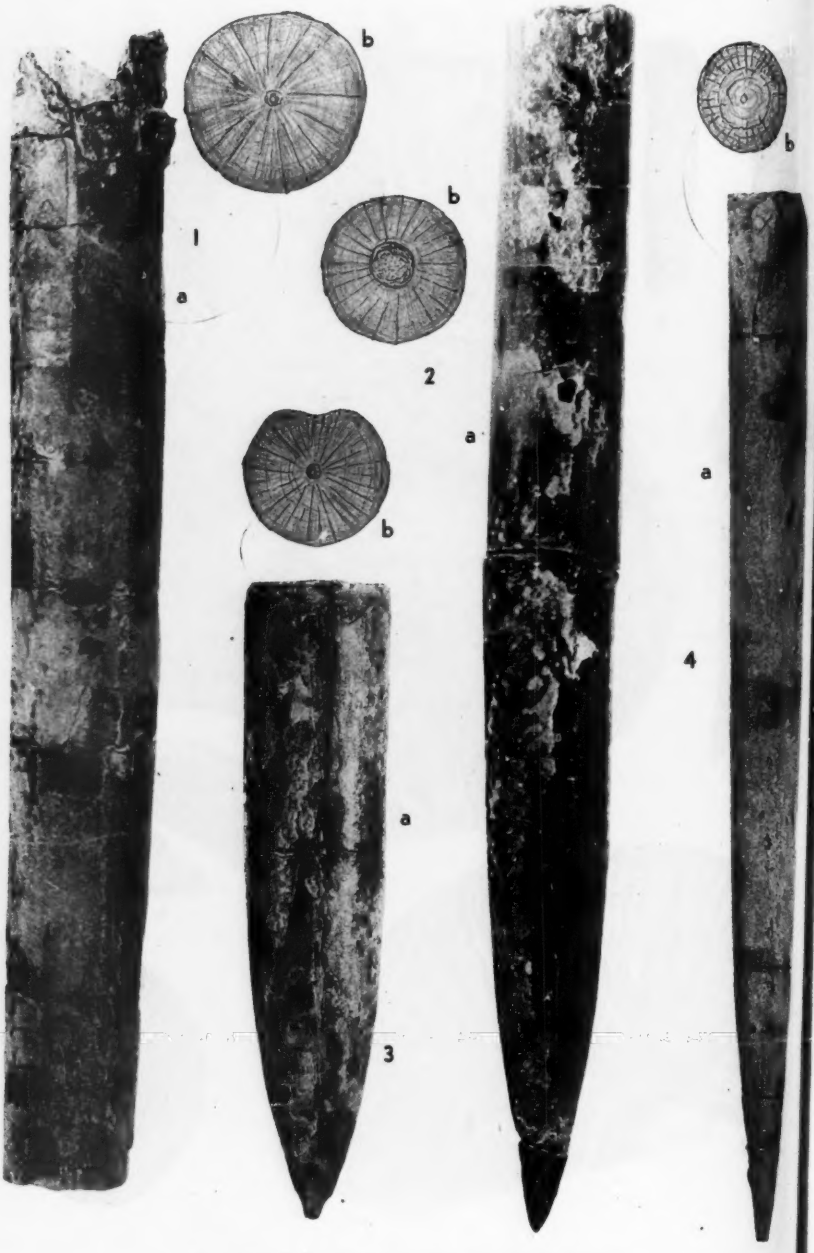
(2) *Bochianites glennensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); (*a*) side view, length, 44 mm., greatest diameter, 10 mm.; (*b*) dorsal view of same; (*c*) enlargement, showing the sculpture. Loc. 28,037 (Calif. Acad. Sci.), in upper part of Newville group. (P. 984.)

(3) *Aulacosphinctes reedi* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.), length, 100 mm.; height of whorl, 37 mm.; thickness, ca. 18 mm. Loc. 28,037 (Calif. Acad. Sci.), in upper part of the Newville group, Tithonian. (P. 978.)

(4) *Aulacosphinctes taffi* Anderson, n. sp.; (*a*) side view, showing ribbing and tubercules on ventrolateral angle, and at dividing points on the ribs; (*b*) oblique view of whorl, showing flattening of ventral zone. Loc. 28,037 (Calif. Acad. Sci.), on Grindstone Creek, western Glenn County; upper part of Newville group, Tithonian. (P. 979.)



UPPER JURASSIC FOSSILS FROM CALIFORNIA



UPPER JURASSIC BELEMNITES FROM CALIFORNIA

PLATE 8.—UPPER JURASSIC BELEMNITES FROM CALIFORNIA

Figure

(1, 2) *Cylindroteuthis occidentalis* Anderson, n. sp.; (1 *a*) paratype (Calif. Acad. Sci. type Coll.), a large fragment; length, 175 mm.; diameter of guard, 24 mm.; (1 *b*) cross section of guard; (2 *a*) holotype (Calif. Acad. Sci. type Coll.); length (incomplete), 191 mm.; diameter of guard, 22 mm.; (2 *b*) cross section of guard. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, western Glenn County, in the upper part of the Newville group, Tithonian. (P. 987.)

(3) *Acroteuthis? watsonensis* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.); length (incomplete), 91 mm.; diameter of guard, 28 mm.; (*b*) cross section of guard. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, western Glenn County, in upper part of the Newville group, Tithonian. (P. 989.)

(4) *Cylindroteuthis klamathonae* Anderson, n. sp.; (*a*) paratype (Calif. Acad. Sci. type Coll.); length (incomplete), 162 mm.; diameter of guard, 15 mm.; (*b*) cross section of guard. Loc. 28,037 (Calif. Acad. Sci.) on Watson Creek, in the upper part of the Newville group, Tithonian. (P. 988.)

PLATE 9.—UPPER JURASSIC BELEMNITES FROM CALIFORNIA

Figure

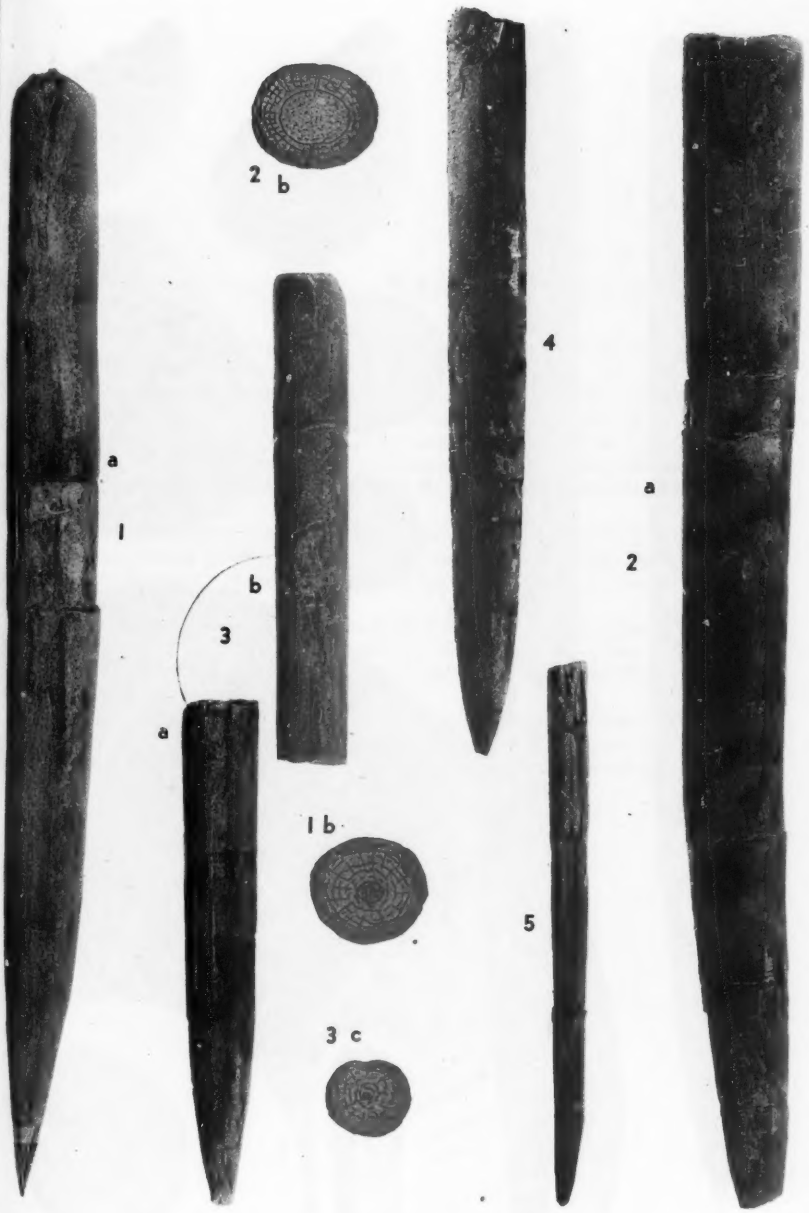
(1) *Cylindroteuthis glennensis* Anderson, n. sp.; (*a*) paratype (Calif. Acad. Sci. type Coll.); length (incomplete), 165 mm.; diameter of guard, 18 mm.; (*b*) cross section of guard. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, in the upper part of the Newville group, Tithonian. (P. 987.)

(2) *Cylindroteuthis knoxvillensis* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.); length, 178 mm.; diameter of guard, 18 mm.; (*b*) cross section of guard near anterior end. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, western Glenn County, in the upper part of the Newville group, Tithonian. (P. 987.)

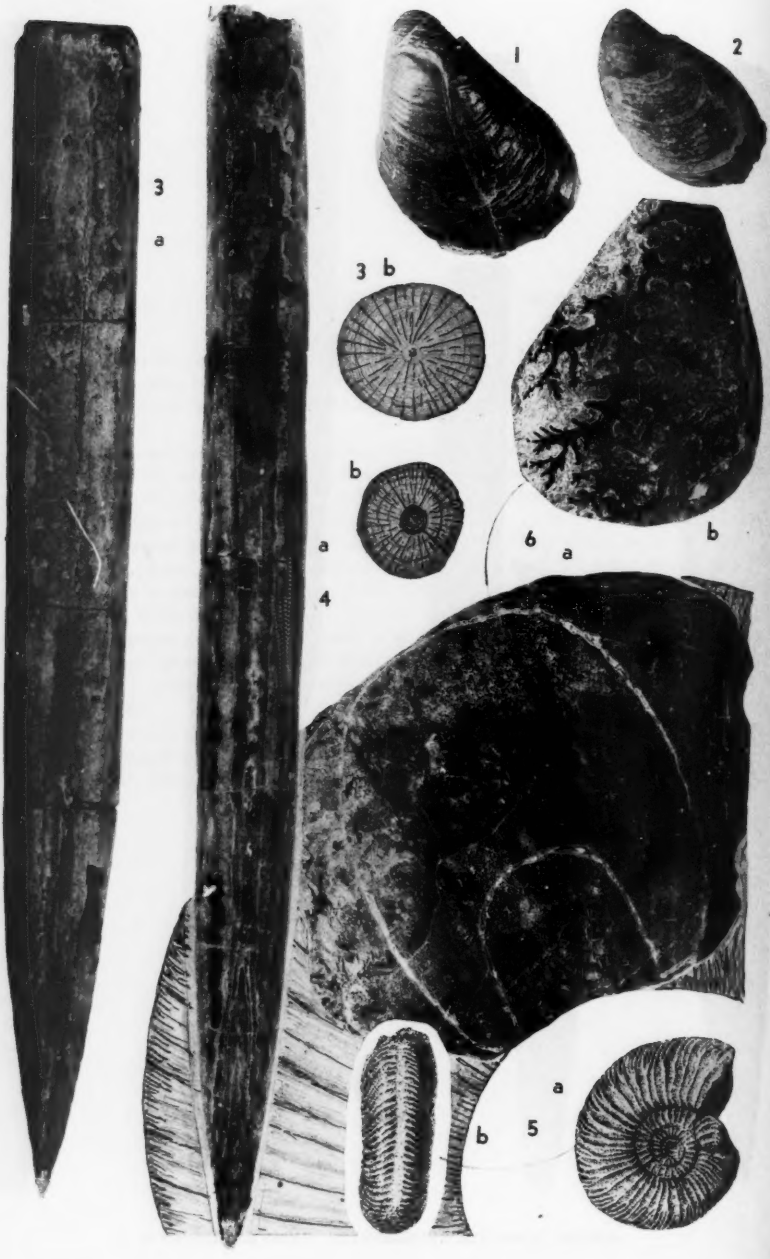
(3) *Cylindroteuthis porrectiformis* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.), length, 76 mm.; diameter, 12 mm.; (*b*) syntype (Calif. Acad. Sci. type Coll.), length, 74 mm.; (*c*) cross section of guard. Loc. 28,037 (Calif. Acad. Sci.), in the upper part of the Newville group, Tithonian. (P. 988.)

(4) *Cylindroteuthis newvillensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); length, 113 mm.; greatest diameter, 13 mm.; section ovate-cylindrical. Loc. 28,628 (Calif. Acad. Sci.), 2 miles south of Paskenta, Tehama County, in the Newville group, Tithonian. (P. 988.)

(5) *Cylindroteuthis clavicula* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); length, 82 mm.; diameter of guard, 6 mm. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, western Glenn County, in the upper part of the Newville group, Tithonian. (P. 989.)



UPPER JURASSIC BELEMNITES FROM CALIFORNIA



UPPER JURASSIC FOSSILS FROM CALIFORNIA

PLATE 10.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

(1) *Aucella* aff. *A. volgensis* Lahusen; example found in the basal beds of the Shasta series in the Arlington district. Berkeley Hills. (P. 972.)

(2) *Aucella weerthi* Pavlow; example found near the head of Blue Canyon, west of the Oake's home, Elder Creek district, in beds of the Newville group, Tithonian. (P. 969.)

(3) *Cylindroteuthis glennensis* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.), showing ventral side of guard; length, 176 mm.; greatest diameter, 20 mm.; (*b*) section of guard near anterior end. Loc. 28,037 (Calif. Acad. Sci.), in the upper part of the Newville group, Tithonian. (P. 987.)

(4) *Cylindroteuthis knoxvillensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); length, 176 mm.; greatest diameter, 18 mm.; (*b*) cross section of guard. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, western Glenn County, in the upper part of the Newville group. (P. 987.)

(5) *Kossmatia dilleri* (Stanton), after Stanton (1895, p. 82, pl. 18, fig. 6, 7); (*a*) right side, showing branching ribs; (*b*) ventral view, showing ventral groove. 3 miles west of Lowry's place on Elder Creek, probably in upper part of the Elder Creek group, Upper Portlandian. (P. 982.)

(6) *Lytoceras huberti* Anderson, n. sp.; (*a*) holotype (Calif. Acad. Sci. type Coll.), showing section of whorl and lateral ornamentation; (*b*) first lateral lobe of the suture line. Loc. 28,037 (Calif. Acad. Sci.), western Glenn County, in the upper part of the Newville group, Tithonian. (P. 978.)

PLATE 11.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

(1, 2) *Phylloceras glennense* Anderson, n. sp.; (1) holotype (Calif. Acad. Sci. type Coll.), large fragment of moderate size, showing bundling of costae near umbilical border; (2) oblique view of periphery of same. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, western Glenn County, in the upper part of the Newville group, Tithonian. (P. 976.)

(3, 4) *Substeueroceras stantoni* Anderson, n. sp.; (3) paratype (Calif. Acad. Sci. type Coll.); (4) fragment of smaller example of same species. Same locality as last. (P. 982.)

(5) *Phylloceras knoxvillense* Stanton; an inner whorl of a larger coil. Same locality as last. (P. 976.)

(6) *Aulacosphinctes watsonensis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); a large fragment, about one-third of a whorl; length, 144 mm.; apparent thickness, 30 mm. Same locality as last.

(7, 8) *Aptycus? knoxvillensis* Stanton, after Stanton (1895, p. 83, Pl. 18, figs. 1, 2). Near Knoxville, Napa County, in the Newville group zone of *Aucella knoxvillensis* n. sp., Tithonian. (P. 985.)

UPPER JURASSIC FOSSILS FROM CALIFORNIA

UPPER JURASSIC AUCELLAE FROM CALIFORNIA

PLATE 12.—UPPER JURASSIC AUCELLAE FROM CALIFORNIA

Figure

(1) *Aucella fischeri* (d'Orbigny); (*a*, *b*) plesiotype (Calif. Acad. Sci. type Coll.); length, 35 mm.; width, 24 mm.; thickness, 17 mm.; (*c*, *d*) smaller example; length, 26 mm. Loc. 28,037 (Calif. Acad. Sci.), in the upper part of the Newville group, in western Glenn County, Tithonian. (P. 970.)

(2) *Aucella occidentalis* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); (*a*) left valve; (*b*) right valve, showing form and relative length; (*c*) rear view, showing thickness of holotype; length, 50 mm.; width, 35 mm.; thickness, 29.5 mm. Loc. 28,037 (Calif. Acad. Sci.), in the upper part of the Newville group, western Glenn County. (P. 971.)

(3) *Aucella* cf. *A. mosquensis* (von Buch); (*a*) left valve, showing form and outline; (*b*) rear view, showing the high arch and thickness of the valve. Sulphur Creek, 4 miles above its mouth, probably in the lower part of the Knoxville series. (P. 966.)

(4) *Aucella attenuata* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); (*a*) left valve, side view; (*b*) rear view; (*c*) rear view of both valves, showing thickness of holotype; length, 33 mm.; width, 14 mm.; thickness of both valves, 15.2 mm. Loc. 3,401 (Calif. Acad. Sci.), 1.5 miles northwest of Cooper's house on the South fork of Elder Creek, Tehama County. Newville group, Tithonian. (P. 970.)

(5) *Aucella fischeri* (d'Orbigny), old and unusual example; (*a*) left valve; (*b*) rear view, showing curvature; length, 45 mm.; maximum width, 30 mm. Loc. 28,037 (Calif. Acad. Sci.), upper part of Newville group, Tithonian. (P. 970.)

(6) *Aucella subinflata* Pavlow; plesiotype (Calif. Acad. Sci. type Coll.); (*a*) left valve, showing outline form; (*b*) rear view of both valves; (*c*) smaller example of left valve; all figures enlarged × 2. Loc. 28,037 (Calif. Acad. Sci.), on Watson Creek, in the upper part of the Newville group, Tithonian. (P. 969.)

PLATE 13.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

(1, 2) *Aulacosphinctes? colusaensis* Anderson, n. sp.; (1) drawings representing the holotype, showing length, width, and ribbing of the same; (1 *a*) showing section of the holotype; length, 63 mm.; width, 25 mm.; greatest thickness, 12–13 mm. (2) Photograph of another fragment, may be a part of holotype, showing sculpture of the same; (2 *b*) portion of suture, including part of lateral lobe and saddle. Bear Creek, 1.3 miles above the mouth of Sulphur Creek, Colusa County, in lower beds of Newville group. Probably Tithonian. (P. 980.)

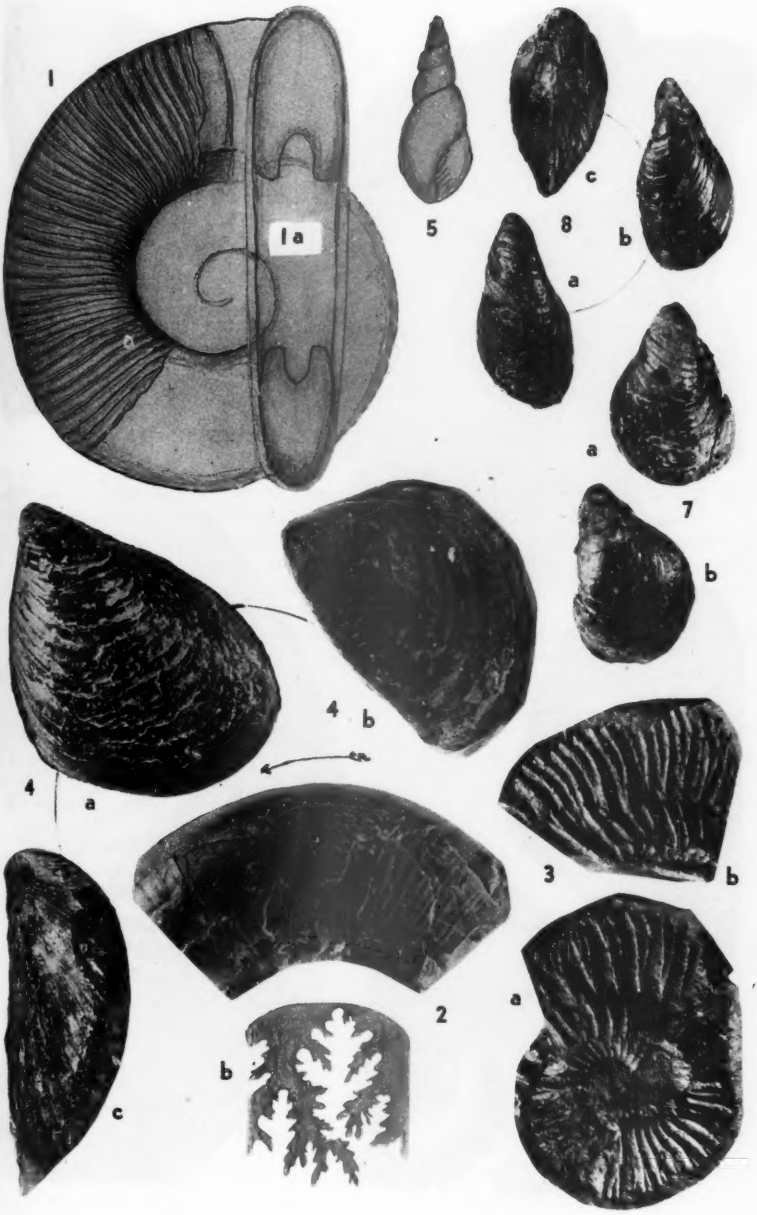
(3) *Aulacosphinctes jenkinsi* Anderson, n. sp.; (*a*) Plaster cast made from rock mold of holotype (Calif. Acad. Sci. type Coll.); greatest diameter, 43 mm.; width of umbilicus, 12 mm.; (*b*) paratype, consisting of a fragmentary rock mold, showing character of ribbing, found with the holotype. Loc. 28,037 (Calif. Acad. Sci.), upper part of the Newville group. Tithonian. (P. 979.)

(4) *Aucella trigonoides* Lahusen; plesiotype (Calif. Acad. Sci. type Coll.); (*a*) left valve, side view; length, 52 mm.; width, 35 mm.; (*b*) right valve of smaller example, length, 45 mm.; (*c*) front view left valve. Same locality as last. (P. 971.)

(5) *Itieria californica* Anderson, n. sp.; drawing of holotype (Calif. Acad. Sci. type Coll.), enlarged × 2.9. Same locality as last. Tithonian. (P. 974.)

(7) *Aucella terebratuloides* Lahusen; (*a*) left valve; (*b*) right valve; length, 38 mm.; width, 17.8 mm.; thickness of both valves, 15 mm. Same locality as last. (P. 971.)

(8) *Aucella tenuicollis* Pavlow; plesiotype (Calif. Acad. Sci. type Coll.); (*a*) left valve; (*b*) right valve of same; (*c*) front view, showing thickness of both valves. Blue Canyon, in the Newville group, Tithonian. (P. 970.)



UPPER JURASSIC FOSSILS FROM CALIFORNIA

UPPER JURASSIC AMMONITES FROM CALIFORNIA

PLATE 14.—UPPER JURASSIC AMMONITES FROM CALIFORNIA

Figure

(1) *Lytoceras* aff. *L. liebigi* (Oppel); fragmentary example, natural size, found at Loc. 28,037 (Calif. Acad. Sci.) in the upper part of the Newville group, Tithonian. (P. 977.)

(2) *Lytoceras* aff. *L. exoticum* (Oppel); (*a*) rock mold; (*b*) plaster cast made from the mold. Loc. 28,037 (Calif. Acad. Sci.), in the upper part of the Newville group, Tithonian. (P. 977.)

(3) *Proniceras?* 5th large fragment. Loc. 28,037 (Calif. Acad. Sci.), in upper part of the Newville group in western Glenn County, Tithonian. (P. 983.)

(4) *Distoloceras* sp., a fragmentary example of Hyatt's genus. Grindstone Creek, 1200 feet west of the iron bridge, associated with *Protacanthodiscus*. Tithonian (?). (P. 983.)

PLATE 15.—UPPER JURASSIC FOSSILS FROM CALIFORNIA

Figure

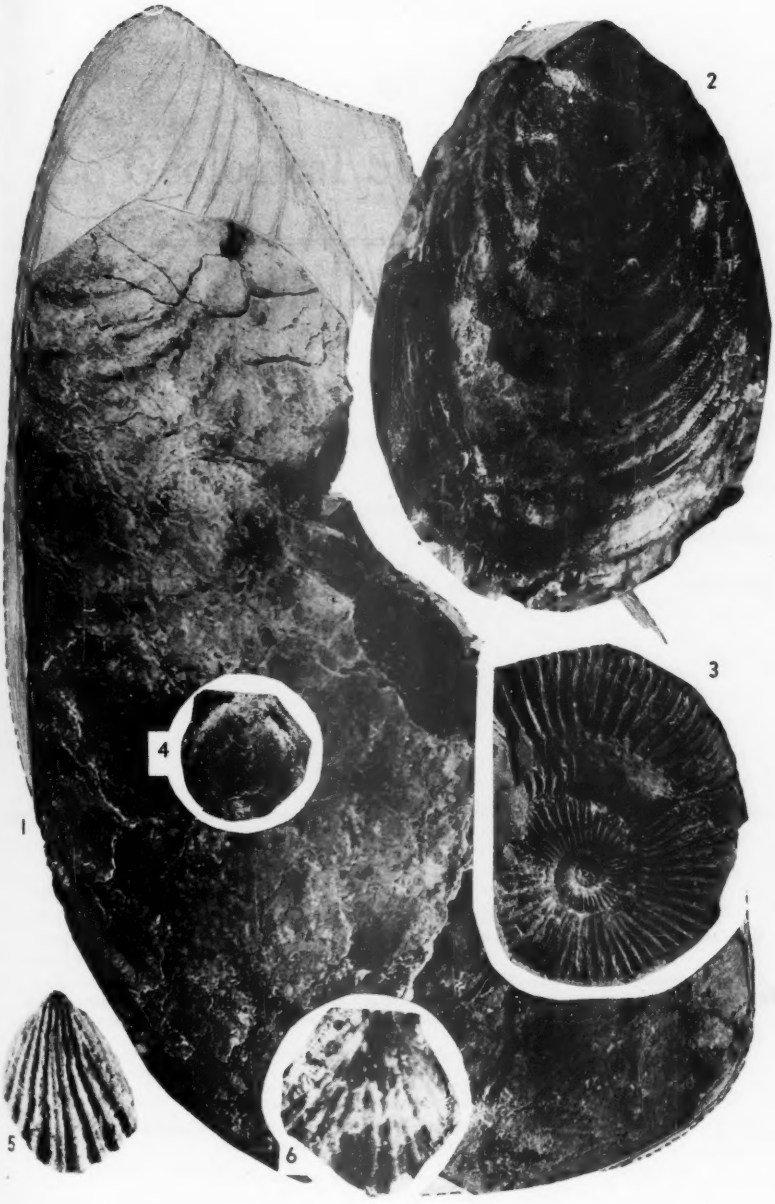
(1) *Inoceramus scotti* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); length (incomplete), 14 inches (355 mm.); greatest width, 9 inches (228 mm.); thickness of both valves, 2 inches (51 mm.). Loc. 28,609 (Calif. Acad. Sci.); in the upper part of the Newville group, on Alder Springs road, 1 mile west of Winslow, western Glenn County. Tithonian. (P. 961.)

(2) *Inoceramus stantoni* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.); length, 85 mm.; width, 50 mm.; apparent thickness, 16 mm. Loc. 28,037 (Calif. Acad. Sci.), on south bank of Grindstone Creek, 1,200 feet west of the iron bridge, Glenn County. Tithonian. (P. 961.)

(3) *Substeueroceras stantoni* Anderson, n. sp.; holotype (Calif. Acad. Sci. type Coll.). Loc. 28,037 (Calif. Acad. Sci.), in the upper part of the Newville group on Watson Creek, western Glenn County. Tithonian. (P. 982.)

(4) *Pecten* (*Syncyclonema*) cf. *concentricum* Koch; right valve; height, 14 mm.; thickness, 3 mm. Loc. 28,609 (Calif. Acad. Sci.), 3.5 miles north of the Winslow bridge, on Alder Springs road, Glenn County. Tithonian. (P. 962.)

(5, 6) *Pteria* (*Oxytoma*) *californica* Anderson, n. sp.; (5) holotype (Calif. Acad. Sci. type Coll.); (6) Paratype (Calif. Acad. Sci. type Coll.); both examples enlarged × 1.6. Upper part of the Newville group, 0.4 mile west of Paskenta, Tehama County. Tithonian. (P. 963.)



UPPER JURASSIC FOSSILS FROM CALIFORNIA